IEc

Assessment of Potential Oil Spill Impacts for the State of Delaware

May 2021

prepared for:

Delaware Department of Natural Resources and Environmental Control

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This report was prepared by IEc using Federal funds under award NA19NOS4190140 from the Delaware Coastal Management Program and the Office for Coastal Management (OCM), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the OCM, NOAA or the U.S. Department of Commerce.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

As Federal policymakers consider making portions of the Atlantic Outer Continental Shelf (OCS) open for offshore oil and gas exploration and development, the Delaware Department of Natural Resources and Environmental Control (DNREC) is seeking to better understand the impacts of oil spills related to this activity, specifically the impact of potential spills on Delaware's coastal communities and the resources upon which they depend. DNREC is also seeking to better understand oil spill risks associated with marine transportation and related activities along the Mid-Atlantic coast. Consistent with these objectives, Industrial Economics, Inc. (IEc) and RPS have conducted an analysis of the trajectory and fate of potential oil spills in the Mid-Atlantic region and the economic impacts of these spills on activities that are reliant on coastal and marine resources. A detailed understanding of these effects will enable Delaware communities and resource managers to plan in advance for oil spill impacts and may also inform the identification and implementation of strategies to increase resiliency to spills.

This report presents the methods and findings of the IEc-RPS analysis, integrating detailed oil fate and transport modeling with the economics of the various activities affected by offshore oil spills. To begin the analysis, this report defines the oil spill scenarios analyzed and describes the methods applied in assessing the fate and transport of spilled oil. Among other factors, the scenarios analyzed vary by spill location, magnitude of spilled oil, and the time of year in which a spill might occur. The report then determines the likely effects of oiling under each scenario to a set of impact categories relevant to Delaware. These include reductions in coastal recreation including beach use, recreational fishing, and recreational boating; reductions in commercial fishing; impacts to maritime shipping; and response costs involved in spill cleanup and abatement of environmental effects. In addition to assessing these changes in activity and, where possible, the welfare effects of these changes,[1] this report also assess the impacts of these changes to Delaware's economy. This economic impact assessment captures effects in directly impacted industries as well as spillover effects to other industries.

[1] Welfare effects refer to the change in well-being of consumers and/or producers.

OIL SPILL SCENARIOS

The socio-economic impacts to Delaware of oil spills occurring near the state's coast depend significantly on the characteristics of individual spills and the fate and transport of oil after a spill occurs. For example, the impacts of a spill for beach use and other forms of coastal recreation are a function of, among other factors, the volume of oil spilled and the degree to which spilled oil reaches the shoreline. If a spill is relatively small (e.g., less than 100 barrels) and ocean currents carry the spilled oil away from the shoreline, recreational impacts are likely to be minimal. In contrast, if a relatively large spill occurs when ocean currents are flowing shoreward, recreational impacts are likely to be much more significant. Given the importance of these factors for the magnitude of a spill's socioeconomic impacts, the analysis of oil spill risk for Delaware begins with the development of precise specifications for the spills to be examined and robust modeling of the fate and transport of the oil spilled under each scenario.[2]

The oil spill scenarios examined in this analysis are defined according to several variables relevant to both the fate and transport of oil and the physical oil spill consequences that determine socioeconomic impacts. These variables are as follows:

Surface versus subsurface spill: The impacts of a spill depend, in part, on whether it is a surface spill (e.g., due to an incident with a tanker carrying crude oil) or a sub-surface spill (e.g., due to a well blowout). The scenarios examined in this analysis include both types.

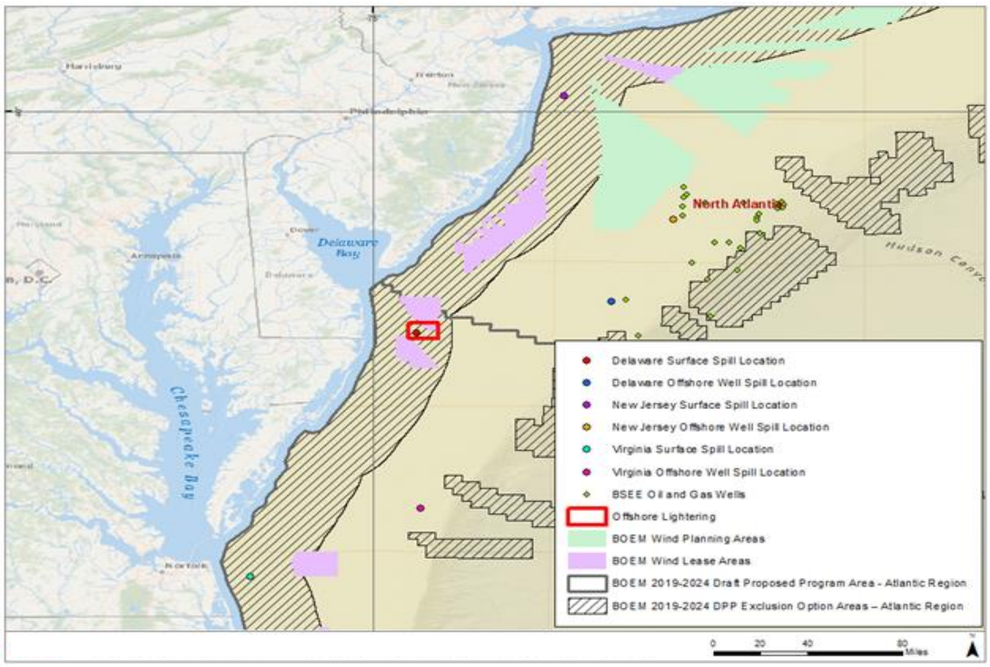
Location: To provide a detailed understanding of the oil spill risks faced by Delaware, this analysis examines potential oil spills at six locations, defined according to both their position along the coast and their distance from shore. With respect to the former, the analysis includes spill locations off the coast of Delaware and sites off the coasts of New Jersey and Virginia. Modeling spills along this stretch of the Mid-Atlantic coast allows the analysis to capture the extent to which spills in the broader region may result in socioeconomic impacts to Delaware. With respect to distance from shore, the analysis models spills occurring both at nearshore sites and at offshore sites for the Delaware, New Jersey, and Virginia locations. Although oil and gas development is unlikely to occur in the nearshore environment, vessels transporting crude oil to shore or to offshore lightering areas would be at risk for collisions and other incidents resulting in a surface spill in these areas. The risk of collisions is of particular concern near Delaware Bay given that it is a major shipping channel. Vessel collisions would be less likely in offshore areas, but a blowout from an exploration or development well could result in a major subsurface spill event in these areas.

Exhibit ES-1 shows the six spill locations chosen for this analysis, along with other spatial information such as the location of existing offshore lightering zones, areas

[2] A more detailed presentation of the oil spill modeling conducted in support of this analysis is available in RPS, *Delaware Department of Natural Resources and Environmental Control (DNREC) Oil Spill Modeling and Impacts Assessment Final Report*, prepared for Industrial Economics and DNREC, 2021.

included in the Bureau of Ocean Energy Management's (BOEM's) 2019-2024 Draft Proposed Program, BOEM wind planning areas, and BOEM wind lease areas. For the Delaware nearshore location, the analysis examines hypothetical spills occurring in the lightering zone located southeast of the entrance to Delaware Bay.[3]

EXHIBIT ES-1. LOCATIONS OF HYPOTHETICAL OIL RELEASES OFF DELAWARE, NEW JERSEY, AND VIRGINIA



Spill size: To capture the potential range of oil spill impacts to Delaware, this study assesses spills of varying size. For each of the nearshore locations, the impacts associated with three spill sizes are assessed: 126 barrels, 2,240 barrels, and 200,000 barrels. For the offshore locations (chosen to capture the effects of a well blowout), this study assesses a single spill size of 900,000 barrels intended to be representative of a well blowout event.

Oil type: For each oil spill scenario, this analysis models the same crude oil type, as the oil source and refinement state are expected to be similar regardless of the location in the Mid-Atlantic. Early oil exploration in the Mid-Atlantic identified a potential for light crudes and condensates to be present in the region (BOEM 2012). Thus, one light crude oil type is modeled in all scenarios, whether as surface releases or as a subsea blowout. Detailed information on the properties and composition of the light crude oil in the Mid-Atlantic, however, is not readily available. In the absence of such information, this analysis uses the properties and composition of oil spilled during the *Deepwater Horizon*

3 The nearshore location for Delaware is the approximate center of a primary offshore lightering track offshore Delaware Bay at 38.4875°N, 74.7334°W.

incident from lease area MC252, which was a light crude with API=37. This crude has been well characterized and is documented in detail in Annex B of RPS (2021).

Spill response actions: The level of shoreline and surface oiling that ultimately results from a spill depends, among other factors, on the steps, if any, taken to mitigate the effects of the spill. This analysis therefore examines impacts for large (200,000 barrel) surface spills both with mitigation and without mitigation. For the mitigated case, the response parameters modeled are surface dispersant, mechanical removal, and in-situ burning (ISB), with assumptions for all three based on the analysis of French-McCay et al. (2017, 2018).

Atmospheric and ocean conditions such as currents and winds: The conditions at the time of a spill and shortly thereafter may significantly affect the fate and transport of spilled oil and, ultimately, the socioeconomic impacts of a spill. For example, winds and currents may carry spilled oil toward coastal population centers (resulting in significant impacts) or out to sea (resulting in less significant impacts). Between these two variables, there are an infinite number of permutations for conditions at the time of a spill. Therefore, to focus the scope of this analysis, worst case conditions were used for each combination of spill location, season, and spill size, based on probabilistic oil spill modeling described in RPS (2021).[4] The worst case was defined according to conditions for the day between 1 April 2018 and 20 April 2020 with conditions leading to the maximum length of shoreline oiling across the entire Mid-Atlantic (not just Delaware).

Based on the information above regarding the selection of the worst-case conditions and the variables for defining individual spills, Exhibits ES-2 through ES-4 summarize each of the spill scenarios analyzed. Each exhibit identifies the simulated spills off a given state's coast. For each state, 20 distinct spill scenarios are analyzed: four low-volume surface spills (all unmitigated), four medium-volume surface spills (all unmitigated), four subsurface blowout scenarios (all unmitigated), and eight high-volume surface spills (four mitigated and four unmitigated).

[4] For the purposes of defining seasons, winter is December through February; spring is March through May; summer is June through August; and fall is September through November.

EXHIBIT ES-2. OIL SPILL SCENARIOS FOR SPILLS OFF DELAWARE'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
DE-1	Offshore Delaware	Surface Unmitigated 126 bbl Release During Winter	Low	2/28/2019
DE-2		Surface Unmitigated 126 bbl Release During Spring	Low	5/25/2018
DE-3		Surface Unmitigated 126 bbl Release During Summer	Low	6/25/2018
DE-4		Surface Unmitigated 126 bbl Release During Fall	Low	10/3/2019
DE-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	2/28/2019
DE-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	5/15/2018
DE-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	6/25/2018
DE-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	10/1/2019
DE-9		Surface Unmitigated 200k bbl Release During Winter	High	2/28/2019
DE-10		Surface Unmitigated 200k bbl Release During Spring	High	5/15/2019
DE-11		Surface Unmitigated 200k bbl Release During Summer	High	6/25/2018
DE-12		Surface Unmitigated 200k bbl Release During Fall	High	10/1/2019
DE-13		Surface Mitigated 200k bbl Release During Winter	High	2/28/2019
DE-14		Surface Mitigated 200k bbl Release During Spring	High	5/15/2019
DE-15		Surface Mitigated 200k bbl Release During Summer	High	6/25/2018
DE-16		Surface Mitigated 200k bbl Release During Fall	High	10/1/2019
DE-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
DE-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/26/2018
DE-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	6/2/2018
DE-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

EXHIBIT ES-3. OIL SPILL SCENARIOS FOR SPILLS OFF NEW JERSEY'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
NJ-1	Offshore New Jersey	Surface Unmitigated 126 bbl Release During Winter	Low	12/7/2018
NJ-2		Surface Unmitigated 126 bbl Release During Spring	Low	5/1/2018
NJ-3		Surface Unmitigated 126 bbl Release During Summer	Low	8/28/2019
NJ-4		Surface Unmitigated 126 bbl Release During Fall	Low	9/28/2019
NJ-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	12/7/2018
NJ-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	5/1/2018
NJ-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	8/28/2019
NJ-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/28/2019
NJ-9		Surface Unmitigated 200k bbl Release During Winter	High	12/7/2018
NJ-10		Surface Unmitigated 200k bbl Release During Spring	High	5/1/2018
NJ-11		Surface Unmitigated 200k bbl Release During Summer	High	8/28/2019
NJ-12		Surface Unmitigated 200k bbl Release During Fall	High	9/27/2019
NJ-13		Surface Mitigated 200k bbl Release During Winter	High	12/7/2018
NJ-14		Surface Mitigated 200k bbl Release During Spring	High	5/1/2018
NJ-15		Surface Mitigated 200k bbl Release During Summer	High	8/28/2019
NJ-16		Surface Mitigated 200k bbl Release During Fall	High	9/27/2019
NJ-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
NJ-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/21/2018
NJ-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	8/9/2019
NJ-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

EXHIBIT ES-4. OIL SPILL SCENARIOS FOR SPILLS OFF VIRGINIA'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
VA-1	Offshore Virginia	Surface Unmitigated 126 bbl Release During Winter	Low	1/13/2020
VA-2		Surface Unmitigated 126 bbl Release During Spring	Low	3/9/2020
VA-3		Surface Unmitigated 126 bbl Release During Summer	Low	6/19/2018
VA-4		Surface Unmitigated 126 bbl Release During Fall	Low	10/13/2019
VA-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	1/13/2020
VA-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	3/9/2020
VA-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	7/19/2018
VA-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/21/2019
VA-9		Surface Unmitigated 200k bbl Release During Winter	High	1/13/2020
VA-10		Surface Unmitigated 200k bbl Release During Spring	High	5/28/2018
VA-11		Surface Unmitigated 200k bbl Release During Summer	High	7/19/2018
VA-12		Surface Unmitigated 200k bbl Release During Fall	High	9/21/2019
VA-13		Surface Mitigated 200k bbl Release During Winter	High	1/13/2020
VA-14		Surface Mitigated 200k bbl Release During Spring	High	5/28/2018
VA-15		Surface Mitigated 200k bbl Release During Summer	High	7/19/2018
VA-16		Surface Mitigated 200k bbl Release During Fall	High	9/21/2019
VA-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/21/2019
VA-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/13/2018
VA-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	8/25/2019
VA-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2019

OIL SPILL MODELING METHODS

This analysis applies the SIMAP modeling system to simulate the fate and transport of spilled oil. SIMAP, as documented in French-McCay (2003, 2004) and French-McCay et al. (2018b) quantifies oil trajectory, concentrations of oil hydrocarbon components as droplet and dissolved phases in the water column, areas swept by floating oil of varying mass concentrations and thicknesses, shorelines oiled to varying degrees, and amount of oil settling to sediments. The SIMAP model has been validated with data from more than 20 large oil spills, including the *Exxon Valdez, North Cape* and *Deepwater Horizon* oil spills (French and Rines 1997; French-McCay 2003, 2004; French-McCay and Rowe 2004; French-McCay et al. 2015, 2016, 2018a,b), as well as test spills designed to verify the model (French et al. 1997). These studies showed that oil trajectories depended primarily on the current and wind data input to the model.

The oil spill modeling results include two key outputs used for the analysis of socioeconomic impacts: (1) length of shoreline with oil exposure exceeding thresholds of concern and (2) area of floating surface oil exceeding thresholds of concern. This analysis uses the former for the assessment of beach recreation and recreational fishing impacts and the latter for the assessment of impacts to commercial fishing, recreational boating, response costs, and shipping. Thresholds of concern were reviewed by French-McCay (2009, 2016) and French-McCay et al. (2018a), based in part on work described in French-McCay (2002, 2003, 2004). Thresholds are generally expressed as an area-based concentration or loading (grams per meter squared [g/m^2]; 1 g/m^2 is approximately 1 micrometer (µm) thick oil, on average, if the oil is not emulsified or up to approximately 6 µm thick if emulsified) of floating or shoreline oil that could potentially adversely affect a resource (French-McCay 2009; French-McCay 2016). Based on the review studies cited above and in accordance with current practice in oil spill risk assessments, the following thresholds of concern are applied in this study:

- **Floating Surface Oil Thickness Thresholds: ≥0.1 g/m^2 (~0.01 µm thick on average over an area)**
    - Effects on socioeconomic resources may occur (e.g., fishing may be prohibited) if oil is visible on the water surface, i.e., ≥0.1 g/m^2. This threshold is used for the socioeconomic impact categories affected by surface water oiling.
- **Shoreline Thickness Thresholds: ≥1 g/m^2 (~1 µm thick on average over an area)**
    - The threshold of 1 g/m^2 represents an oil amount that would appear as a dull brown color.
    - Effects on socioeconomic resources may occur (e.g., reduced beach use) above a threshold of 1 g/m^2.

RECREATION IMPACTS

The categories of coastal and marine recreation considered in this analysis include beach use, recreational fishing, and recreational boating. For each form of recreation, the analysis assesses the spill-related reduction in recreational activity and the economic welfare loss associated with such reductions. The latter is defined as the value that individual users derive from pursuing an outdoor recreational activity, net of the costs of doing so.

For each category of recreation, this analysis begins with specification of baseline levels of use in each season, measured in user days. Because there is potential for double counting between recreation categories, the baseline use for each category is defined so as to minimize the potential for double counting. For example, baseline use for recreational fishing is restricted to fishing activity in non-beach areas since beach-based fishing is likely reflected in beach use statistics. Similarly, because fishing on charter boats or party boats is captured in the recreational boating category, recreational fishing in this analysis is restricted to exclude boat-based fishing. For all three categories of recreation, the seasonal estimates of activity for Delaware are spatially distributed to different zones within Delaware's coastal and marine environments. Exhibit ES-5 shows the annual and seasonal level of recreational activity for beach use, recreational fishing, and marine recreational boating along Delaware's coast.

EXHIBIT ES-5. BASELINE LEVELS OF MARINE RECREATIONAL USE ALONG DELAWARE COAST

RECREATIONAL ACTIVITY	WINTER	SPRING	SUMMER	FALL	ANNUAL
Beach Use	587,696	1,428,273	6,901,714	2,510,325	**11,428,008**
Recreational Fishing	65,973	208,037	448,217	223,990	**946,218**
Recreational Boating	45,402	843,725	2,380,697	1,571,272	**4,841,097**

To estimate the reduction in use for each spill scenario and recreational activity, this analysis examines the spatial overlap between the recreation zones for each activity and potential oiling under each of the modeled spill scenarios. In areas where oiling occurs under a given scenario, the estimated reduction in recreational activity is based on either use reductions following similarly sized spills in the past or the duration of area closures (e.g., beach closures) associated with past spill events. Following this approach, the number of lost user days may vary by season even among scenarios with similar amounts of oiling. This is due to differences in the intensity of coastal and marine recreation during the course of the year. Due to uncertainty regarding reductions in use, reductions were estimated as a range in some cases. To assess the economic value of reductions in recreational activity, this analysis applies estimates of the value per recreational user day obtained from the literature, as summarized in Exhibit ES-6.

EXHIBIT ES-6. ECONOMIC VALUE PER USER DAY OR TRIP (2019$)

RECREATIONAL ACTIVITY	VALUE
Beach Use ($/user day)	$42.14
Recreational Fishing ($/trip)	$20.95
Recreational Boating ($/trip)	$30.04

Applying the approach described above, the estimated welfare losses associated with the reductions in coastal and marine recreation under each oil spill scenario are shown in Exhibit ES-7. Consistent with the focus of this study, all estimated effects are related to changes in recreational activity occurring in Delaware. Recreational impacts in other states are not reflected in these estimates, even for the spill locations off the coasts of New Jersey and Virginia. As shown in the exhibit, the estimated welfare losses related to recreation tend to be highest when a spill occurs during the summer. This is due to both higher recreational activity in the summer and ocean current and wind patterns resulting in greater shoreline oiling under the summer spill scenarios.

Exhibit ES-7 also shows that recreational impacts are more significant for the spill scenarios off the coast of Delaware than for the New Jersey or Virginia scenarios. This reflects the greater extent of shoreline oiling along Delaware's coast for spills that occur in close proximity to Delaware. In addition, for some of the New Jersey and Virginia spill scenarios, the results show no impact, such as the fall and winter surface spills off the Virginia coast. Under these scenarios, oil is not projected to reach the Delaware coastline based on the oil spill modeling described above.

EXHIBIT ES-7. ESTIMATED WELFARE LOSSES - COASTAL AND MARINE RECREATION (MILLIONS OF 2019$)

Lost Use Value due to Oiling - All Recreational Activity						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$6.6 - $8.2	$32.1 - $35.9	$5.6 - $7	-
	Surface	Unmitigated 2,240bbl	$15.2 - $17.1	$71.9 - $76.3	$25.6 - $29.5	$0 - $0.1
	Surface	Unmitigated 200,000bbl	$92.9 - $95.5	$155.1 - $160	$93.7 - $99.5	$0 - $0.1
	Surface	Mitigated 200,000bbl	$84.7 - $86.2	$150.3 - $155.5	$92 - $98.9	$0 - $0.1
	Subsurface	Unmitigated 900,000bbl	$255.7 - $258.9	$257.6 - $262.5	$140 - $144.8	$166.6 - $167.9
New Jersey	Surface	Unmitigated 126bbl	-	$32 - $35.9	-	-
	Surface	Unmitigated 2,240bbl	-	$68.8 - $75.8	$0 - $2.8	$0 - $0.1
	Surface	Unmitigated 200,000bbl	-	-	$2.4 - $4.6	$0.1 - $0.2
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	$256.3 - $259.2	$255.3 - $261.1	$143.5 - $145.7	$194.3 - $193.2
Virginia	Surface	Unmitigated 126bbl	-	$0 - $2.1	-	-
	Surface	Unmitigated 2,240bbl	-	$0 - $4.3	-	-
	Surface	Unmitigated 200,000bbl	-	$0.9 - $7	-	-
	Surface	Mitigated 200,000bbl	-	$101.4 - $102.7	-	-
	Subsurface	Unmitigated 900,000bbl	$250.2 - $253.6	$97 - $107.4	$44.7 - $51.5	$86.8 - $87

As expected, the larger spill sizes in a given location generally result in more significant recreational impacts than smaller spills. This is due to more widespread shoreline oiling under these scenarios as well as the extended, multi-season use reduction effects associated with larger spills. One exception to this pattern, however, is the surface spills occurring during the summer off the coast of New Jersey. As shown in Exhibit ES-7, this analysis projects recreational impacts (in Delaware) for the 126- and 2,240-barrel spills off New Jersey but not the 200,000-barrel spills. This reflects how the worst-case spill is defined for each scenario. As described above, the specification for the worst-case scenario is based on the maximum shoreline oiled *across the entire Mid-Atlantic region* rather than the maximum shoreline oiling on Delaware's coast. In the case of the 200,000-barrel summer spill off the coast of New Jersey, the maximum shoreline oiling is projected when currents and the wind carry the oil northward, causing significant oiling along the coast of New Jersey and the southern coast of Long Island, but no oiling to Delaware's coast. As a sensitivity analysis, the appendix to this report presents recreational impacts under an alternative specification of the 200,000-barrel summer spills off the coast of New Jersey, using the same conditions as assumed for the 126- and 2,240-barrel worst-case spills.

COMMERCIAL FISHING IMPACTS

Impacts to Delaware's commercial fishing industry are defined as lost landings revenue relative to baseline levels of landings revenue for Delaware-based commercial fishers. This analysis focuses solely on the impacts to Delaware's commercial fishery and does not account for potential damages to other, nearby fisheries (e.g., New Jersey, New York, or Virginia).

As an initial step in estimating commercial fishing losses, this analysis specifies baseline landings for Delaware's commercial fishing industry. Based on data from the Delaware Department of Natural Resources and Environmental Control (DNREC) on commercial landings (dollars and pounds) for 2018 by species, Exhibit ES-8 presents the top ten species by landings revenue, as well as total landings for the state. As indicated in the exhibit, the total value of Delaware's commercial fishery is roughly $11.67 million per year as of 2018. This means that if an oil spill resulted in the closure of the entirety of the fishery for a year, lost revenues would not exceed $11.67 million.

After compiling data on the total size of the Delaware fishery, the annual landings in Exhibit ES-8 were apportioned temporally across the year and spatially within the Atlantic and Delaware Bay. The temporal allocation across months of the year was based on the commercial fishing season for each species. To allocate landings spatially, this analysis relies on a raster dataset developed by the NOAA Northeast Fisheries Science Center (NFSC) that shows the spatial representation of self-reported Vessel Trip Report

(VTR) fishing locations and the landings revenue associated with commercial fishing trips.[5]

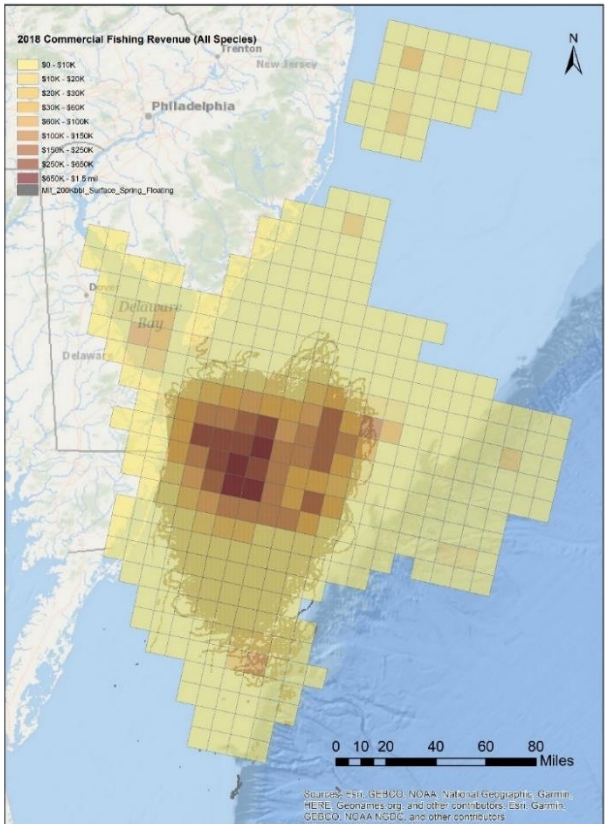
EXHIBIT ES-8. DNREC 2018 COMMERICIAL LANDINGS, TOP TEN SPECIES ($2019)

SPECIES	VALUE ($2019)	POUNDS
Blue Crab	$8,565,130	4,263,213
Knobbed Conch	$719,680	294,605
Oyster	$616,538	106,904
Black Sea Bass	$613,655	169,078
Striped Bass	$567,098	155,028
Horseshoe Crab Male	$224,554	378,195
American Eel	$98,505	31,378
Smooth Conch	$76,941	14,398
Hard Clam	$74,310	20,236
American Lobster	$41,282	14,592
All others	$76,231	280,094
Total (all species):	**$11,673,922**	**5,727,721**

To assess the impacts of individual spill scenarios on Delaware fisheries, the extent of oiling under each oil spill scenario was intersected in GIS with the spatial distribution of commercial fishery landings. For each spill scenario, surface oiling in coastal waters was projected for a set of 6.5-by-6.5-mile grid cells. A given grid cell was considered oiled above a threshold of concern if the total oil concertation in that grid cell exceeded the threshold value of 0.1 g/m^2. The gridded projection of surface oiling above this threshold was overlaid on the spatially allocated landings data to identify areas where commercial fishing activity would be affected by oiling. For example, Exhibit ES-9 provides a visual representation of the oiling data overlaid on the gridded revenue data for the mitigated 200,000-barrel spring oiling scenario off the coast of Delaware.

[5] See Benjamin et al. (2018).

EXHIBIT ES-9. ILLUSTRATION OF COMERCIAL FISHING OVERLAY ANALYSIS



The commercial fisheries in areas projected to be oiled under a spill scenario were assumed to be closed for a certain period of time following the spill. The assumed duration of closure varied based on the size of the spill, with larger spills resulting in longer closure periods. Due to the uncertainty in closure duration, this analysis utilized a range of closure durations for most spill sizes. The ranges chosen for each spill size category were based on a review of fishery closures implemented in response to past oil spills.

Based on this approach, Exhibit ES-10 presents the estimated reduction in landings revenues for Delaware fisheries by spill scenario. As shown in the exhibit, impacts are more significant for the spill scenarios occurring off the coast of Delaware than for the spills occurring off New Jersey or Virginia. This reflects the spatial distribution of surface oiling relative to high-intensity fishing areas in Delaware's coastal waters. A large portion of Delaware's commercial fishing activity occurs at the mouth of the Delaware Bay as well as the area directly to the east of the Bay. All of the surface oil scenarios for Delaware affect these areas to some degree while some of the scenarios for other spill locations are not projected to result in oil reaching these areas. As an example, as shown in Exhibit ES-10, there are several surface oiling scenarios for the Virginia spill location that do not result in any impacts to Delaware's commercial fishery.

EXHIBIT ES-10. LOST COMMERCIAL FISHING REVENUE (MILLIONS OF 2019$)

Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	$0.72 - $3.24	$0.09 - $0.46	$0.27 - $0.69	-
	Surface	Unmitigated 200,000bbl	$3.67 - $11.19	$3.38 - $11.32	$2.19 - $9.36	$0.56 - $4
	Surface	Mitigated 200,000bbl	$3.51 - $10.69	$3.18 - $10.67	$1.88 - $8.03	$0.53 - $3.84
	Subsurface	Unmitigated 900,000bbl	$11.63	$11.63	$11.26	$11.58
New Jersey	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	$0.01 - $0.04	$0 - $0.05	-	$0 - $0.05
	Surface	Unmitigated 200,000bbl	$0.06 - $0.19	$0.03 - $0.09	$2.16 - $9.22	$1.5 - $10.82
	Surface	Mitigated 200,000bbl	$0.06 - $0.18	$0.01 - $0.02	$0.03 - $0.13	$0.02 - $0.13
	Subsurface	Unmitigated 900,000bbl	$11.45	$11.37	$11.34	$11.51
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	$0 - $0.01	-
	Surface	Unmitigated 200,000bbl	$0.01 - $0.02	$3.3 - $11.07	$0.06 - $0.26	-
	Surface	Mitigated 200,000bbl	-	$2.28 - $7.63	$0.05 - $0.22	-
	Subsurface	Unmitigated 900,000bbl	$11.35	$0.49	$1.30	$0.61

Estimates of lost commercial fishing revenues also tend to be highest for spills occurring during the spring and summer. This is due to the timing of the open commercial fishing seasons for Delaware's more profitable fisheries (e.g., blue crab, which is open from the beginning of March through November). For the unmitigated 200,000-barrel scenarios off the coast of New Jersey, however, lost revenues are higher for spills occurring in the fall and winter than for spills occurring in the spring and summer. As described in the section on recreational impacts above, this reflects how the worst-case spill is defined for each scenario.

In general, the larger unmitigated spills in each location result in more significant commercial fishing impacts than the smaller unmitigated spills. This is due to more widespread oiling in Delaware coastal waters as well as the extended, multi-season, or even year-long, closure durations. For Virginia spills, however, the impacts associated with the 900,000-barrel summer blowout scenario are estimated to be less than impacts for both 200,000-barrel scenarios (mitigated and unmitigated). This also reflects how the worst-case spill is defined, as well as the assumed spill location for the blowout scenarios relative to the surface scenarios. Because the blowout scenarios are assumed to occur far offshore, the worst-case conditions for these spills differ from those for surface spills occurring closer to shore. For the summer blowout scenario off the coast of Virginia, the conditions resulting in the worst case (defined as maximum shoreline oiling) push the spilled oil southward, causing significant oiling along and near the Virginia and North Carolina coasts, but result in minimal oiling off the coast of Delaware. In contrast, the worst case for the surface spills is under conditions that push spilled oil northward, toward the fishing grounds of Delaware's commercial fishing industry.

COMMERCIAL SHIPPING IMPACTS

Oil spills and the resulting surface oil sheens present unique challenges to the commercial shipping industry. Ships passing through affected waters can carry oil with them along their route, potentially contaminating ports or sensitive environmental areas. Travelling through surface sheens could also cause damage to vessel function, and large enough quantities could produce hazardous fumes that may pose a health risk to crewmembers. To avoid these potential risks in the immediate aftermath of a spill, commercial shipping vessels may choose to either 1) delay progress on their route until the oil slick is removed or 2) reroute their path to circumnavigate the polluted area. Both avoidance strategies can result in significant delays to commercial shipping traffic. Even small spills can prevent commercial traffic from travelling through affected shipping lanes if travel restrictions or temporary closures are imposed on affected areas. Whether a vessel remains in place to await the clearance of oil or decides to seek an alternate route, it will still incur fuel and other operating costs (e.g., crew wages, maintenance, etc.).

This analysis examines the effects of the oil spill scenarios described above on commercial shipping traffic passing through Delaware ports, specifically the Port of Wilmington and the Port of New Castle. For each vessel diverted or delayed from its original route, costs are incurred due to the additional consumption of fuel, the prolonged operations of the vessel, and the pilotage costs associated with diverting from the original route. The incremental fuel consumption, operating, and pilotage costs are largely dependent on the vessel size and design, vessel speed, duration of delay or alternate voyage, and type and price of fuel used.

Accounting for each of these factors, Exhibit ES-11 presents the estimated increase in shipping costs for each oil spill scenario. As indicated by the "Not Blocked" notation for several scenarios, the oil spill modeling projects that the entrance to Delaware Bay would not be obstructed by spilled oil under several scenarios. For these scenarios, this analysis estimates zero cost impact related to commercial shipping activity at Delaware ports. For the other scenarios, this analysis estimates a range of commercial shipping cost impacts, with the range reflecting uncertainty regarding the duration of the blockage to Delaware Bay.

EXHIBIT ES-11. INCREASE IN COMMERCIAL SHIPPING COSTS BY SPILL SCENARIO (MILLIONS OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	\$0.06 - \$0.31	\$0.06 - \$0.31	\$0.06 - \$0.31	Not Blocked
	Surface	Unmitigated 200,000bbl	\$0.21 - \$0.57	\$0.21 - \$0.57	\$0.21 - \$0.57	Not Blocked
	Surface	Mitigated 200,000bbl	\$0.13 - \$0.43	\$0.13 - \$0.43	\$0.13 - \$0.43	Not Blocked
	Subsurface	Unmitigated 900,000bbl	\$0.57 - \$0.9	\$0.57 - \$0.9	\$0.57 - \$0.9	\$0.57 - \$0.9
New Jersey	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	\$0.06 - \$0.31	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	\$0.21 - \$0.57
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	\$0.57 - \$0.9	\$0.57 - \$0.9	\$0.57 - \$0.9	\$0.57 - \$0.9
Virginia	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	\$0.21 - \$0.57	Not Blocked	Not Blocked
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	\$0.57 - \$0.9	Not Blocked	Not Blocked	Not Blocked

Among the three states examined (i.e., Delaware, Virginia, and New Jersey), the number of spill scenarios resulting in the blockage of Delaware Bay is highest for the Delaware spill location, with 13 scenarios resulting in blockage. While the New Jersey and Virginia scenarios would result in fewer blockage instances (six and two, respectively), the duration of blockage associated with each spill size is assumed to be equal across all scenarios. The vessel data does not indicate substantial seasonal shifts in vessel entrances, so costs associated with commercial traffic delays and diversions are assumed to be constant across all seasons in the event of a blockage.

RESPONSE COSTS

In the event of an offshore oil spill, response teams act quickly to minimize or prevent injury to natural resources. This analysis assesses the costs of spill response activities for each of the oil spill scenarios listed in Exhibits ES-2 to ES-4 above. The response costs examined include the removal of oil directly from the water, washed up on the shoreline, in ports, and in sensitive environments such as wetlands. Approaches to removal factored into the response cost calculations include dispersants, in-situ burning, and mechanical removal using tools such as skimmers and booms.

This analysis also allocates the calculated response cost to different types of payors based on historical trends. The Oil Pollution Act (OPA) of 1990 designates that the party found primarily responsible for an oil spill is liable for the costs of cleanup; however, in the event that the responsible party cannot be identified, the federal government covers response costs, drawing on resources from the Oil Spill Liability Trust Fund (OLSTF). Federal, state, local, and private entities engaged in cleanup operations are encouraged to submit reimbursement claims to the U.S. Coast Guard's National Pollution Funds Center, which adjudicates claims and, when appropriate and in accordance with OPA requirements, approves the disbursement of funds from the OLSTF.

To estimate response costs for each oil spill scenario, this analysis applies two approaches. Drawing on the published literature, the first approach involves the application of a series of multipliers to a predetermined base response cost per barrel corresponding to characteristics such as the type of shoreline oiled (e.g., sandy beach versus rocky surface). This approach is applied to the 126-barrel and 2,240-barrel spills. For the second approach, which is applied to larger spills (i.e., 200,000 barrels or more), this analysis applies cost per barrel values derived from the experience of the *Exxon Valdez* and *Deepwater Horizon* spills.

Exhibit ES-12 presents the estimated cost of spill response activities on or along Delaware's coast for each spill, with estimates presented as a range for the 200,000-barrel and 900,000-barrel scenarios to account for the significant uncertainty regarding the response costs for spills of such large magnitude. The values in Exhibit ES-12 include costs borne by the State of Delaware as well as costs borne by other parties (e.g., the federal government and responsible parties). Based on data compiled by Helton and Penn (1999) and data reported by the U.S. Coast Guard's National Pollution Funds Center, which administers the Oil Spill Liability Trust Fund, state governments incur 10.4 percent of response costs. Based on this value, Exhibit ES-13 presents the portion of response costs likely to be borne by the State of Delaware.

EXHIBIT ES-12. COSTS RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS (MILLIONS OF 2019$)

Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	$2.0	$2.8	$2.3	-
	Surface	Unmitigated 200,000bbl	$514 - $948	$609 - $1,124	$215 - $396	-
	Surface	Mitigated 200,000bbl	$482 - $1,363	$305 - $863	$261 - $739	-
	Subsurface	Unmitigated 900,000bbl	$1,681 - $3,103	$1,615 - $2,981	$1,645 - $3,036	$2,984 - $5,507
New Jersey	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	$1.6	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	$12.3 - $22.7
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	$1,933 - $3,568	$838 - $1,546	$2,820 - $5,204	$3,165 - $5,842
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	-	-
	Surface	Unmitigated 200,000bbl	-	$35 - $64	-	-
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	$440 - $811	-	-	-

EXHIBIT ES-13. COSTS BORNE BY THE STATE OF DELAWARE RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS (MILLIONS OF 2019$)

Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	$0.2	$0.3	$0.2	-
	Surface	Unmitigated 200,000bbl	$53.6 - $98.9	$63.5 - $117	$22.4 - $41.3	-
	Surface	Mitigated 200,000bbl	$50.2 - $142	$31.8 - $89.9	$27.2 - $77.1	-
	Subsurface	Unmitigated 900,000bbl	$175 - $324	$168 - $311	$172 - $317	$311 - $574
New Jersey	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	$0.2	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	$1.3 - $2.4
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	$202 - $372	$87.3 - $161	$294 - $543	$330 - $609
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	-	-
	Surface	Unmitigated 200,000bbl	-	$3.6 - $6.7	-	-
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	$45.8 - $84.6	-	-	-

As both of the above exhibits show, response costs for oiling in the Delaware coastal zone are highest under the largest spill scenarios. Response costs are particularly high for the 900,000-barrel blowout scenarios, even though the modeled location for these scenarios is considerably farther from shore than the surface spill scenarios. At the other end of the spectrum, response costs for oiling in the Delaware coastal zone are estimated as $0 for each of the 126-barrel spill scenarios. In actuality, individual spills of approximately 126 barrels could result in response costs related to oiling in Delaware's coastal zone, but the oil spill modeling described above suggests that 126-barrel spills in the specific locations chosen for this analysis would likely results in little to no response for oiling along Delaware's shoreline.

In addition to the 126-barrel spills, the results in Exhibits ES-12 and ES-13 show that response costs associated with oiling in Delaware's coastal zone are projected as $0 for most of the 126-barrel, 2,240-barrel, and 200,000-barrel scenarios off the coasts of New Jersey and Virginia. Although most of these spills will result in response costs, the oil spill modeling described above suggests that there would be no surface oiling above the 0.1 g/m^2 threshold in the Delaware coastal zone under most of these scenarios. Exceptions include the unmitigated 200,000-barrel summer spill off the coast of Virginia, the unmitigated 200,000-barrel winter spill off the coast of New Jersey, and the 2,240-barrel summer spill off the coast of New Jersey.

ECONOMIC AND FISCAL IMPACTS

Policymakers and the public may be interested in understanding how spill-related changes in activity in the coastal and marine environment affect the health of the Delaware economy as well as the State's finances. This analysis assesses these economic and fiscal impacts, measured in terms of employment, state level gross domestic product (GDP), labor income, and revenues collected by the State. The scope of analysis for these effects includes impacts related to changes in coastal and marine recreation and changes in commercial fishing activity. Although spill-related changes in commercial shipping activity and spill response may have implications for the Delaware economy, the magnitude of these effects is highly uncertain and therefore excluded from the assessment of economic and fiscal impacts.

To assess the economic and fiscal impacts associated with each oil spill scenario, this analysis applies the IMPLAN input-output model. Input-output models are a well-established framework for assessing the economic and fiscal impacts associated with a change in expenditures for one or several industries across multiple sectors of the economy. Using detailed data on inter-industry relationships, input-output models estimate how a positive or negative shock in one industry (e.g., a change in output) cascades across the broader economy. Thus, in addition to capturing direct economic impacts for industries with reduced (or increased) production, input-output models capture spillover effects to other industries. These spillover effects include indirect impacts and induced impacts. Indirect impacts reflect inter-industry purchases and arise from firms purchasing inputs from their suppliers. For example, in the context of expenditures on meals at restaurants, indirect impacts would include the employment associated with producing the meat and poultry used as ingredients in restaurant meals. Induced impacts, by contrast, result from wages paid to workers, who may spend these wages on consumer electronics, clothing, etc. Again, in the context of expenditures on restaurant meals, induced effects include the economic impacts associated with servers, cooks, and other restaurant workers spending their earnings.

Like most input-output models, IMPLAN estimates economic impacts in terms of changes in employment, labor income, value added,[6] and output, and distinguishes between direct, indirect, and induced effects. The model also estimates changes in tax revenues collected by various levels of government. IMPLAN reports its results at the 3- to 4-digit NAICS level for the agricultural and service sectors, and at the 4- to 5-digit NAICS level for manufacturing industries. In the current version of IMPLAN, this amounts to 546 industry sectors. The geographic scope of IMPLAN may be modified to accommodate the needs of a specific analysis. Model runs can be conducted nationally, for regional groupings of states, individual states, groups of counties within states, or for individual counties. The IMPLAN analysis presented here is for the State of Delaware as a whole. The input-output data within IMPLAN are derived from County Business Pattern data published by the U.S. Census Bureau, the U.S. Bureau of Economic Analysis' (BEA's) Regional Economic Accounts, and the Bureau of Labor Statistics' Census of Employment and Wages.

The results of the economic and fiscal impact analysis are presented in Exhibits ES-14 through ES-17. The range of impacts presented in each exhibit reflects the underlying ranges in recreational and commercial fishing impacts presented above. As indicated in all four exhibits, the patterns of impact closely mirror those presented above for coastal and marine recreation and commercial fishing. The estimated economic impacts of spills are generally highest for oil spills occurring off the coast of Delaware, reflecting the more significant reductions in recreational and commercial fishing activity associated with these scenarios relative to those off the coasts of New Jersey and Virginia. The economic impacts of spills are also higher for spills occurring in the spring and summer than spills occurring in the fall or winter, consistent with the temporal distribution of recreational and, to a lesser extent, commercial fishing activity during the course of the year. The results in the exhibits also show that economic impacts are, in most cases, higher for larger spills than smaller spills.

[6] Value added is the degree to which the value of a good is increased at each link in the supply chain, exclusive of initial costs. For example, value added for the restaurant industry includes the value associated with preparing meals from purchased ingredients and serving those meals to customers. The cost of the food ingredients obtained from suppliers, however, is not included in the restaurant industry's value added. Gross domestic product (GDP) is a measure of value added.

EXHIBIT ES-14. NEGATIVE EMPLOYMENT IMPACTS FOR DELAWARE BY SPILL SCENARIO (PERSONS EMPLOYED)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	137 - 171	656 - 740	114 - 142	0 - 1
	Surface	Unmitigated 2,240bbl	331 - 445	1,481 - 1,596	532 - 633	0 - 2
	Surface	Unmitigated 200,000bbl	2,015 - 2,283	3,286 - 3,622	1,989 - 2,311	15 - 106
	Surface	Mitigated 200,000bbl	1,830 - 2,055	3,160 - 3,467	1,938 - 2,256	14 - 102
	Subsurface	Unmitigated 900,000bbl	5,610 - 5,710	5,636 - 5,772	3,201 - 3,323	3,757 - 3,801
New Jersey	Surface	Unmitigated 126bbl	-	653 - 741	-	0 - 1
	Surface	Unmitigated 2,240bbl	0 - 1	1,415 - 1,577	0 - 60	1 - 4
	Surface	Unmitigated 200,000bbl	2 - 5	1 - 2	106 - 336	41 - 285
	Surface	Mitigated 200,000bbl	2 - 5	0 - 1	1 - 3	1 - 3
	Subsurface	Unmitigated 900,000bbl	5,627 - 5,716	5,597 - 5,740	3,290 - 3,356	4,342 - 4,305
Virginia	Surface	Unmitigated 126bbl	-	0 - 43	-	-
	Surface	Unmitigated 2,240bbl	-	0 - 91	0 - 0	-
	Surface	Unmitigated 200,000bbl	0 - 1	105 - 434	2 - 7	-
	Surface	Mitigated 200,000bbl	-	2,139 - 2,307	1 - 6	-
	Subsurface	Unmitigated 900,000bbl	5,471 - 5,554	2,046 - ,2265	982 - 1,126	1,838 - 1,842

EXHIBIT ES-15. NEGATIVE GDP IMPACTS FOR DELAWARE BY SPILL SCENARIO (MILLIONS OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$8 - $10.2	$38.5 - $43.9	$6.7 - $8.6	$0 - $0.1
	Surface	Unmitigated 2,240bbl	$19.7 - $27.1	$87.5 - $94.8	$31.4 - $38	$0 - $0.1
	Surface	Unmitigated 200,000bbl	$119.2 - $136.5	$194.7 - $216.3	$117.4 - $138.4	$1 - $7
	Surface	Mitigated 200,000bbl	$108.2 - $122.7	$186.8 - $207	$114.2 - $134.9	$0.9 - $6.7
	Subsurface	Unmitigated 900,000bbl	$331.7 - $337.6	$335 - $343.3	$191 - $198.6	$222.2 - $224.8
New Jersey	Surface	Unmitigated 126bbl	$0	$38.3 - $44	$0	$0 - $0.1
	Surface	Unmitigated 2,240bbl	$0 - $0.1	$83.1 - $93.5	$0 - $4	$0 - $0.3
	Surface	Unmitigated 200,000bbl	$0.1 - $0.3	$0.1 - $0.2	$7 - $22.2	$2.7 - $18.8
	Surface	Mitigated 200,000bbl	$0.1 - $0.3	$0 - $0	$0.1 - $0.2	$0 - $0.2
	Subsurface	Unmitigated 900,000bbl	$332.6 - $337.9	$332.1 - $341.1	$196.6 - $200.5	$256.4 - $254.3
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $2.9	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $6	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$6.9 - $28.6	$0.1 - $0.4	$0
	Surface	Mitigated 200,000bbl	$0	$126.7 - $137.7	$0.1 - $0.4	$0
	Subsurface	Unmitigated 900,000bbl	$323.1 - $328.4	$119.9 - $134.3	$57.7 - $67.2	$107.7 - $107.9

EXHIBIT ES-16. NEGATIVE LABOR INCOME IMPACTS IN DELAWARE BY SPILL SCENARIO (MN. OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$5 - $6.3	$24.1 - $27.4	$4.2 - $5.3	$0 - $0
	Surface	Unmitigated 2,240bbl	$12.3 - $16.7	$54.7 - $59.1	$19.6 - $23.6	$0 - $0.1
	Surface	Unmitigated 200,000bbl	$74.5 - $84.9	$121.5 - $134.5	$73.4 - $85.9	$0.6 - $4.1
	Surface	Mitigated 200,000bbl	$67.6 - $76.3	$116.7 - $128.6	$71.5 - $83.8	$0.5 - $4
	Subsurface	Unmitigated 900,000bbl	$207.4 - $211.2	$208.8 - $214	$118.8 - $123.5	$138.9 - $140.6
New Jersey	Surface	Unmitigated 126bbl	$0	$24 - $27.4	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$52.1 - $58.4	$0 - $2.3	$0 - $0.2
	Surface	Unmitigated 200,000bbl	$0.1 - $0.2	$0 - $0.1	$4.1 - $13.1	$1.6 - $11.1
	Surface	Mitigated 200,000bbl	$0.1 - $0.2	$0	$0 - $0.1	$0 - $0.1
	Subsurface	Unmitigated 900,000bbl	$208 - $211.4	$207.3 - $212.8	$122.3 - $124.8	$160.5 - $159.1
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $1.7	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $3.5	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$4.1 - $16.9	$0.1 - $0.3	$0
	Surface	Mitigated 200,000bbl	$0	$79.1 - $85.6	$0.1 - $0.2	$0
	Subsurface	Unmitigated 900,000bbl	$202.1 - $205.3	$75.4 - $83.9	$36.3 - $41.8	$67.7 - $67.9

EXHIBIT ES-17. REDUCTION IN DELAWARE STATE GOVERNMENT REVENUE BY SCENARIO (MN. OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0.3 - $0.3	$1.3 - $1.5	$0.2 - $0.3	$0 - $0
	Surface	Unmitigated 2,240bbl	$0.7 - $0.9	$2.9 - $3.2	$1 - $1.3	$0 - $0
	Surface	Unmitigated 200,000bbl	$4 - $4.5	$6.5 - $7.2	$3.9 - $4.6	$0 - $0.2
	Surface	Mitigated 200,000bbl	$3.6 - $4.1	$6.2 - $6.9	$3.8 - $4.5	$0 - $0.2
	Subsurface	Unmitigated 900,000bbl	$11 - $11.2	$11.2 - $11.5	$6.4 - $6.6	$7.3 - $7.4
New Jersey	Surface	Unmitigated 126bbl	$0	$1.3 - $1.5	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$2.8 - $3.1	$0 - $0.2	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0.2 - $0.8	$0.1 - $0.6
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$11 - $11.2	$11.1 - $11.4	$6.6 - $6.7	$8.5 - $8.4
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $0.1	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $0.2	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0.2 - $1	$0	$0
	Surface	Mitigated 200,000bbl	$0	$4.2 - $4.6	$0	$0
	Subsurface	Unmitigated 900,000bbl	$10.7 - $10.9	$4 - $4.5	$1.9 - $2.3	$3.6 - $3.6

CHAPTER 1 | INTRODUCTION

As Federal policymakers consider making portions of the Atlantic Outer Continental Shelf (OCS) open for offshore oil and gas exploration and development, the Delaware Department of Natural Resources and Environmental Control (DNREC) is seeking to better understand the impacts of oil spills related to this activity, specifically the impact of potential spills on Delaware's coastal communities and the resources upon which they depend. DNREC is also seeking to better understand oil spill risks associated with marine transportation and related activities along the Mid-Atlantic coast. Consistent with these objectives, Industrial Economics, Inc. (IEc) and RPS have conducted an analysis of the trajectory and fate of potential oil spills in the Mid-Atlantic region and the economic impacts of these spills on activities that are reliant on coastal and marine resources. A detailed understanding of these effects will enable Delaware communities and resource managers to plan in advance for oil spill impacts and may also inform the identification and implementation of strategies to increase resiliency to spills.

This report presents the methods and findings of the IEc-RPS analysis, integrating detailed oil fate and transport modeling with the economics of the various activities affected by offshore oil spills. To begin the analysis, this report defines the oil spill scenarios analyzed and describes the methods applied in assessing the fate and transport of spilled oil. Among other factors, the scenarios analyzed vary by spill location, magnitude of spilled oil, and the time of year in which a spill might occur. The report then determines the likely effects of oiling under each scenario to a set of impact categories relevant to Delaware. These include reductions in coastal recreation including beach use, recreational fishing, and recreational boating; reductions in commercial fishing; impacts to maritime shipping; and response costs involved in spill cleanup and abatement of environmental effects. In addition to assessing these changes in activity and, where possible, the welfare effects of these changes,[7] this report also assess the impacts of these changes to Delaware's economy. This economic impact assessment captures effects in directly impacted industries as well as spillover effects to other industries.

This report is organized according to the impact categories identified above. Chapter 2 summarizes the scenario development and the oil spill modeling approach. Chapter 3 describes the impacts to coastal recreation. Impacts to commercial fishing are presented in Chapter 4, and impacts to maritime shipping are described in Chapter 5. Chapter 6

[7] Welfare effects refer to the change in well-being of consumers and/pr producers.

includes the estimated costs of spill response. To conclude, Chapter 7 presents an analysis of the economic impacts associated with changes in these activities.

CHAPTER 2 | OIL SPILL SCENARIOS AND MODELLING

The socio-economic impacts to Delaware of oil spills occurring near the state's coast depend significantly on the characteristics of individual spills and the fate and transport of oil after a spill occurs. For example, the impacts of a spill for beach use and other forms of coastal recreation are a function of, among other factors, the volume of oil spilled and the degree to which spilled oil reaches the shoreline. If a spill is relatively small (e.g., less than 100 barrels) and ocean currents carry the spilled oil away from the shoreline, recreational impacts are likely to be minimal. In contrast, if a relatively large spill occurs when ocean currents are flowing shoreward, recreational impacts are likely to be much more significant. Given the importance of these factors for the magnitude of a spill's socioeconomic impacts, the analysis of oil spill risk for Delaware begins with the development of precise specifications for the spills to be examined and robust modeling of the fate and transport of the oil spilled under each scenario.[8]

SPECIFICATION OF SPILL SCENARIOS

The oil spill scenarios examined in this analysis are defined according to several variables relevant to both the fate and transport of oil and the physical oil spill consequences that determine socioeconomic impacts. These variables are as follows:

- ***Surface versus subsurface spill:*** The impacts of a spill depend, in part, on whether it is a surface spill (e.g., due to an incident with a tanker carrying crude oil) or a sub-surface spill (e.g., due to a well blowout).
- ***Location:*** The proximity of a spill to coastal and marine resources used by human populations (e.g., commercial fishing grounds) is also a key factor in assessing spill risk, with close proximity to such resources generally associated with higher risk.
- ***Spill size:*** All else equal, the volume of oil spilled clearly and directly affects the length of shoreline oiled as a result of a spill and the size of the surface sheen in affected waters.
- ***Oil type:*** The type of crude oil spilled is also relevant to the consequences of a spill, as an oil's API gravity (i.e., whether it is a light or heavy crude) can affect

[8] A more detailed presentation of the oil spill modeling conducted in support of this analysis is available in RPS (2021).

the speed at which the oil volatizes after being spilled and how far the oil is transported.

- ***Spill response actions:*** The level of shoreline and surface oiling that ultimately results from a spill depends, among other factors, on the steps, if any, taken to mitigate the effects of the spill. This analysis considers both mitigated and unmitigated spill scenarios.
- ***Atmospheric and ocean conditions such as currents and winds:*** These conditions affect the behavior of spilled oil, and each also varies over time at a given location in the water.

The assumptions for each of these variables are described below.

SURFACE VERSUS SUB-SURFACE SPILLS

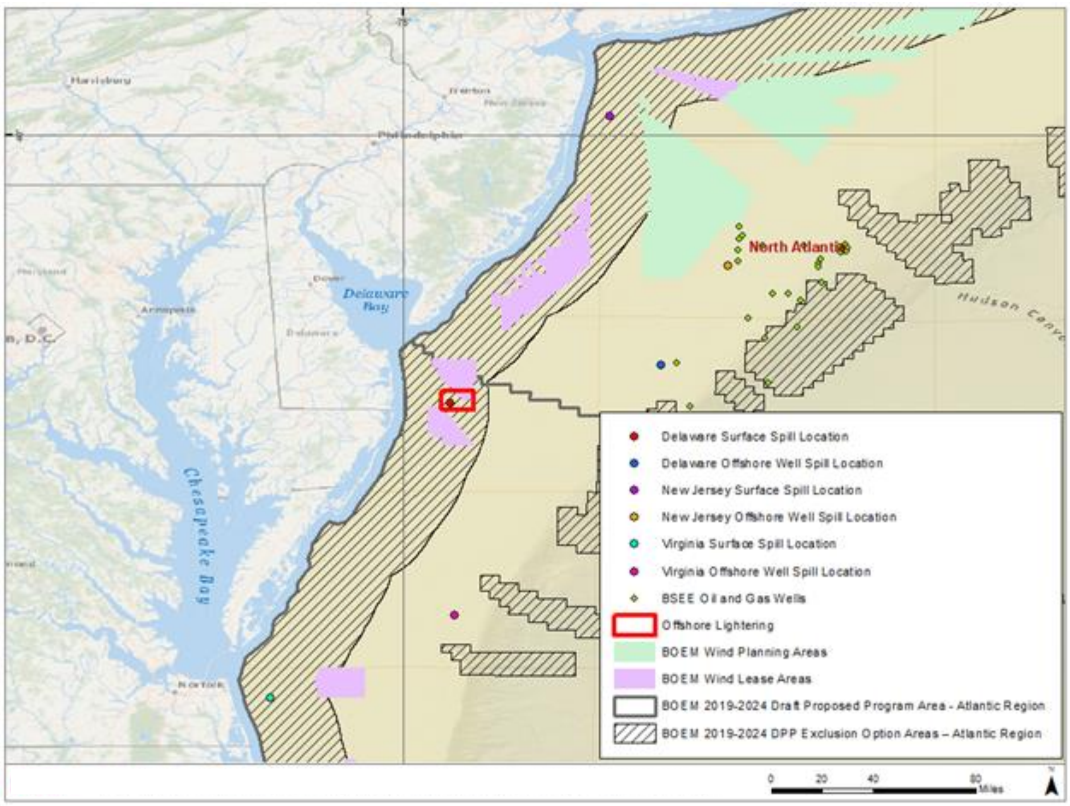
This analysis considers both surface spills and subsurface spills. Not only are both possible in the context of offshore oil and gas development (i.e., tanker spills on the surface and blowout events for the subsurface), but the fate and transport of oil depends on whether oil is spilled on the surface or below the surface. For example, gravitational spreading occurs very rapidly (within hours) to a minimum thickness for a spill on the water surface. Thus, the area exposed to evaporation is high compared to when the oil was first released. In contrast, when a subsurface spill occurs, droplets of varying size are formed, with the smallest droplets remaining in the water longer and potentially dissolving into the water at depth. These factors affect both the extent of shoreline oiling and the extent of surface oiling.

SPILL LOCATION

To provide a detailed understanding of the oil spill risks faced by Delaware, this analysis examines potential oil spills at six locations, defined according to both their position along the coast and their distance from shore. With respect to the former, the analysis includes spill locations off the coast of Delaware and sites off the coasts of New Jersey and Virginia. Modeling spills along this stretch of the Mid-Atlantic coast allows the analysis to capture the extent to which spills in the broader region may result in socioeconomic impacts to Delaware. With respect to distance from shore, the analysis models spills occurring both at nearshore sites and at offshore sites for the Delaware, New Jersey, and Virginia locations. Although oil and gas development is unlikely to occur in the nearshore environment, vessels transporting crude oil to shore or to offshore lightering areas would be at risk for collisions and other incidents resulting in a surface spill in these areas. The risk of collisions is of particular concern near Delaware Bay given that it is a major shipping channel. Vessel collisions would be less likely in offshore areas, but a blowout from an exploration or development well could result in a major spill event in these areas.

Exhibit 2-1 shows the six spill locations chosen for this analysis, along with other spatial information such as the location of existing offshore lightering zones, areas included in the Bureau of Ocean Energy Management's (BOEM's) 2019-2024 Draft Proposed Program, BOEM wind planning areas, and BOEM wind lease areas. For the Delaware nearshore location, the analysis examines hypothetical spills occurring in the lightering zone located southeast of the entrance to Delaware Bay.[9] While no major spills have occurred in this area, this location was chosen due to the potential increase in spill probability associated with offshore oil and gas development. If lightering operations were to intensify at this location due to offshore oil and gas activity, the increased number of oil transfers and increase in vessel traffic would create additional opportunities for a spill to occur. The choice of potential spill sites nearshore New Jersey and nearshore Virginia also reflect vessel traffic in these areas. Exhibit 2-2, which highlights the density of vessel traffic off the coasts of both states and off Delaware, shows that the nearshore sites off the coasts of New Jersey and Virginia are in high-traffic areas where the risks of collision are high relative to other areas.[10] For all three nearshore locations, the sites selected for analysis are located outside BOEM wind planning areas and BOEM wind lease areas.

EXHIBIT 2-1. LOCATIONS OF HYPOTHETICAL OIL RELEASES OFF DELAWARE, NEW JERSEY, AND VIRGINIA



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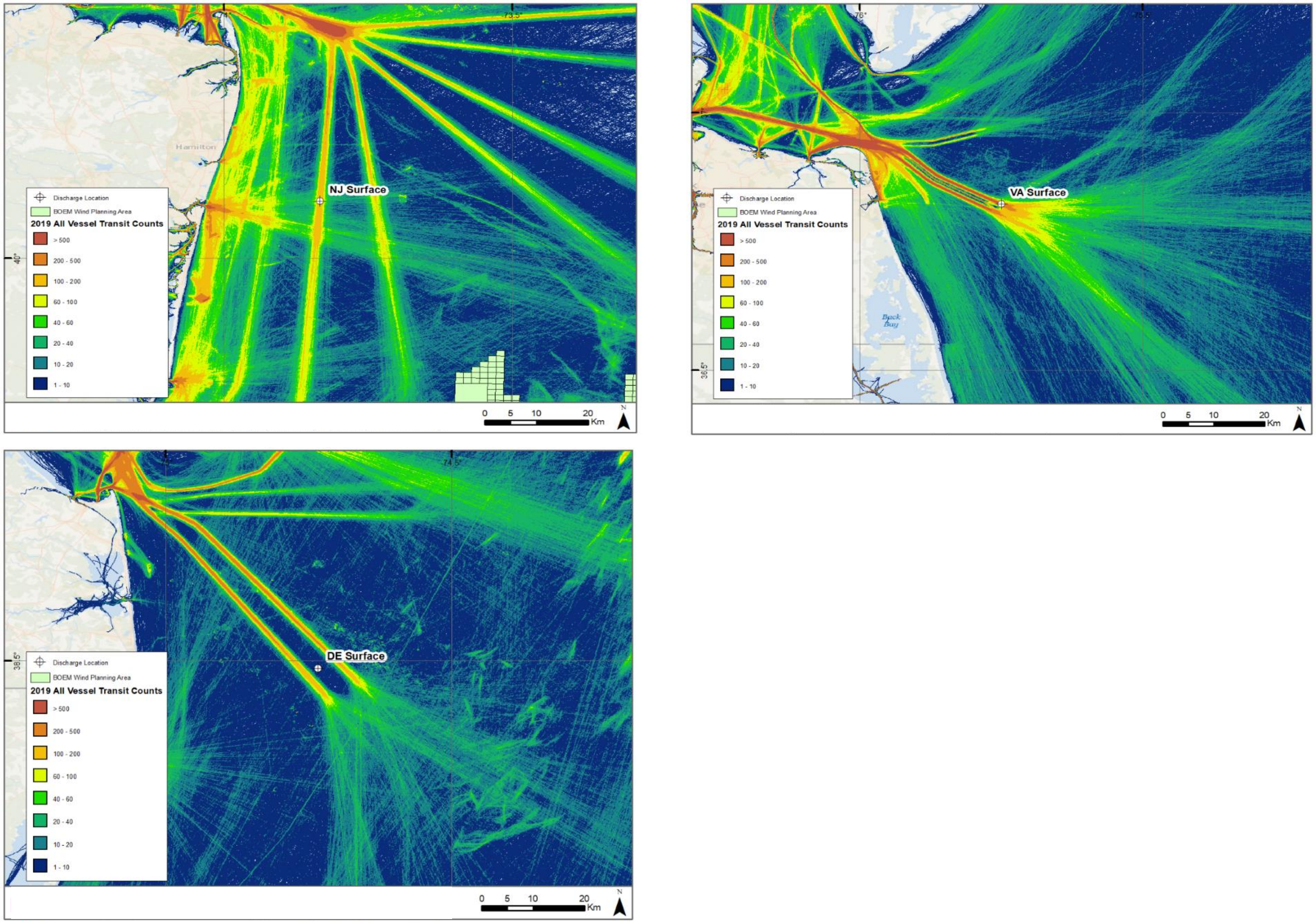
9 The nearshore location for Delaware is the approximate center of a primary offshore lightering track offshore Delaware Bay at 38.4875°N, 74.7334°W.

10 The nearshore locations for New Jersey and Virginia are at 40.1113°N, 73.8329°W and 36.8231°N, 75.7494°W, respectively.

EXHIBIT 2-2. VESSEL TRAFFIC NEAR THE COASTS OF NEW JERSEY, VIRGINIA, AND DELAWARE



The offshore locations chosen off Delaware, New Jersey, and Virginia represent hypothetical well sites for offshore oil and gas development. The analysis of sub-surface spills resulting from well blowouts focuses on these three locations. As represented by the green dots in Exhibit 2-1, the Delaware and New Jersey sites are located in close proximity to exploration wells drilled in these areas in the 1980s and earlier.[11] While there has historically been no well drilling activity off Virginia's coast, the offshore site near Virginia is situated a similar distance from shore and at a similar water depth as the offshore sites for Delaware and New Jersey.[12]

SPILL SIZE

To capture the potential range of oil spill impacts to Delaware, this study assesses spills of varying size. For each of the nearshore locations, the impacts associated with three spill sizes are assessed. For the offshore locations (chosen to capture the effects of a well blowout), this study assesses a single spill size that differs from those modeled for the nearshore locations. The spill volumes chosen are based on U.S. Coast Guard (USCG) spill response planning volumes and BOEM National Environmental Policy Act (NEPA) planning documents.

USCG Spill Response Planning Volumes

USCG Spill response planning volumes (33 CFR §155.1020, 33 CFR §154.1020, and 33 CFR §155.1050) are sometimes used for oil spill risk analyses of spills into U.S. waters. Planning volumes for offshore and coastal marine areas are classified as:

- Average Most-Probable Discharge (AMPD): 50 barrel (bbl) or 1 percent of a facility's worse-case discharge (WCD)[13]
- Maximum Most-Probable Discharge (MMPD; Vessel): 2,500 bbl of oil for vessels with an oil cargo capacity equal to or greater than 25,000 bbl or 10 percent of fuel/cargo capacity up to 2,500 bbl
- Worst-Case Discharge (WCD; Vessel): Entire contents of oil cargo and/or fuel capacity

BOEM NEPA Practices

In its most recent NEPA planning documents for evaluating potential oil spills related to Outer Continental Shelf (OCS) oil and gas activities[14], BOEM reported the median size of large spills (defined as those ≥1,000 bbl) that occurred during 1996-2010 as 2,240 bbl (BOEM 2017b, e). This size was calculated based on the nine spills (both platforms/rigs and pipelines) that occurred during this timeframe and did not include the *Deepwater*

[11] The Delaware offshore site is located in Wilmington Canyon at 38.7017°N, 73.5403°W. The New Jersey offshore site location is at 40.1113°N, 73.8329°W.

[12] The Virginia offshore site is at 37.2886°N, 74.7109°W.

[13] One barrel is equal to 42 gallons.

[14] https://www.boem.gov/nepaprocess

Horizon (DWH) oil spill. BOEM (2017b, e) reported the median size of the large spills (>1000 bbl) from platforms was 5,066 bbl and from pipelines was 1,720 bbl, while spills from other sources were much smaller. BOEM (2017c) reported that the maximum spill volume from a platform (not including DWH) was 7,000 bbl, and that from a pipeline was 1,200 bbl. The median spill size for spills 50-999.9 bbl was 126 bbl (BOEM, 2017c).

BOEM (2017a) published a separate report with its analysis of catastrophic spill events, which would include high-volume extended releases (such as blowouts) due to natural (e.g., hurricane) or human (error or terrorism) cause. In BOEM's assessment, if a blowout were to occur in shallow water (<1,000 ft, 305 m), it could take two weeks to three months to stop the spillage. If a blowout were to occur in deep water (>1,000 ft), BOEM estimated that it could take two weeks to four months to stop the spillage. The floating oil could persist in the environment for one to two months after the release is stopped. In its assessment, BOEM (2017a) assumed 30,000 bbl/day for a shallow water blowout and 30,000 – 60,000 bbl/day for a deep water blowout (the midpoint of which, 45,000 bbl/day, has been assumed in recent deep water modeling work (French-McCay et al. 2018a, based on BOEM, 2013). Offshore of Delaware, the 60 meter depth contour is approximately 30-50 nautical mi [nm] (35-58 mi) offshore. Thus, the potential area for development and a blowout would be classified as shallow water.

Tankers

The largest tankers delivering crude to the Delaware River refineries are about 150,000 dead weight ton (dwt), with vessel size varying between 85,000 and 150,000 dwt. These tankers are classified as Suezmax. However, occasionally a Very Large Crude Carrier (VLCC) or Ultra Large Carrier (ULCC) is brought into Delaware Bay in a partially laden condition and completely offloaded by barge at Big Stone Anchorage (Riker et al. 1981). One dwt is equivalent to approximately 6.3 bbl. Thus, the maximum crude oil cargo of one Suezmax vessel is ~945,000 bbl, and the cargo of a VLCC is ~2 million bbl.

Oil Spill Volumes Selected

Drawing on the information above, the largest (nearshore) surface spill volume examined in this analysis is based on a 10 percent loss of a tanker cargo of crude oil, whereas the medium and small surface spill oil volumes are based on BOEM NEPA practice. For the offshore blowout scenario, the assumed spill volume is consistent with BOEM's (2017a) assumptions for shallow water blowouts.

- *High volume surface spill:* Assuming VLCCs would be loaded (reverse-lightered) at the lightering area off Delaware Bay and 10 percent of the cargo were spilled (based on the USCG MMPD planning volume calculation method, which would be an assumption of 2 out of 20 tanks of a typical VLCC being breached), **200,000 bbl** would be released (assumed over 1 hour). The spilled oil is tracked for 30 days after the release ends.

- *Medium volume surface spill:* Based on recent BOEM NEPA practice, this analysis assumes **2,240 bbl** are released over 1 hour and tracked for 30 days. This is similar to an MMPD as per the USCG Spill Response Plan guidance.

- *Low volume surface spill:* This analysis assumes **126 bbl** released over 1 hour, tracked for 30 days after release ends (based on the median size spill for spills in the 50-999.9 bbl range; BOEM 2017b).
- *Well blowout (sub-surface spill):* Based on BOEM (2017a) for a shallow water blowout, this analysis assumes **30,000 bbl/day over 30 days (900,000 bbl in total)** and tracked for 45 days after release ends. Note that this spill duration is within the possible range but not worst case based on BOEM (2017a).

As context for these spill volumes, the *T/V Presidente Rivera* spill (1989) resulted in the release of approximately 7,300 barrels of No. 6 fuel oil into the Delaware River (NOAA 1989), and the *M/T Athos I* released approximately 6,300 barrels of crude oil into the Delaware River and nearby tributaries in 2004 after an anchor punctured the bottom of the vessel (NOAA 2020).

OIL TYPE

For each oil spill scenario, this analysis models the same crude oil type, as the oil source and refinement state are expected to be similar regardless of the location in the Mid-Atlantic. Early oil exploration in the Mid-Atlantic identified a potential for light crudes and condensates to be present in the region (BOEM 2012). Thus, one light crude oil type is modeled in all scenarios, whether as surface releases or as a subsea blowout. Detailed information on the properties and composition of the light crude oil in the Mid-Atlantic, however, is not readily available. In the absence of such information, this analysis uses the properties and composition of oil spilled during the *Deepwater Horizon* incident from lease area MC252, which was a light crude with API=37. This crude has been well characterized and is documented in detail in Annex B of RPS (2021).

SPILL RESPONSE ACTIONS

This analysis examines impacts for large (200,000 barrel) surface spills both with mitigation and without mitigation. For the mitigated case, the response parameters modeled are surface dispersant, mechanical removal, and in-situ burning (ISB), with assumptions for all three based on the analysis of French-McCay et al. (2017, 2018):

Surface Application of Dispersants*:* This analysis assumes that sufficient dispersant supplies are available to treat all actionable floating oil and that application is not restricted. The geographic area where surface dispersant is used is assumed to be within pre-approval areas in Area Contingency Plans. Thus, this analysis assumes that dispersant is not used (1) within a five nautical mile radius exclusion zone of the release site, (2) in less than 10 meters of water, or (3) within three nautical miles of a shoreline. With respect to timing, this analysis assumes that aerial dispersant application occurs beginning on day two of the spill event at an effective application rate of 1 part dispersant to 20 parts oil (dispersant-to-oil ratio [DOR] = 1:20) for 12 hours (daylight) each day. The dispersant application is assumed effective when oil thickness exceeds 8 µm (0.0003 in, NOAA, 2010) and on weathered and emulsified oil up to a viscosity of 20,000 centipoise (cP). These assumptions are consistent with a recent oil spill modeling risk assessment study conducted with industry, government, and non-governmental organization stakeholders' input (French-McCay et al. 2018, Bock et al. 2018, Walker et al. 2018).

Mechanical Removal and ISB: During the *Deepwater Horizon* oil spill response, once fully mobilized, virtually all available equipment in the mainland U.S. for mechanical removal and ISB was mobilized and applied. Thus, the achieved removal rates reflected the performance of the full fleet of equipment in the U.S. operating at full capacity. Drawing on this experience, the modeled capacity used for this study is the maximum monthly average volume removal rate per day observed from the *Deepwater Horizon* response, which, based on Lehr et al. (2010), was 10,829 bbl/day of oily water in June 2010, equivalent to 2,166 bbl/day of oil removed. In June 2010, ISB removed an average of 5,372 bbl of oil per day (Lehr et al. 2010). For the current analysis, mechanical removal and ISB operations are assumed to begin on day two of the spill event and occur 12 hours a day, except for in a five nautical mile exclusion zone around the release site, when environmental conditions are suitable (Etkin et al. 2006) on oil > 8 µm thick (NOAA, 2010). These assumptions are consistent with a recent oil spill modeling risk assessment study conducted with industry, government, and non-governmental organization stakeholders' input (French-McCay et al. 2018a; Bock et al. 2018; Walker et al. 2018).

ATMOSPHERIC AND OCEAN CONDITIONS

The conditions at the time of a spill and shortly thereafter may significantly affect the fate and transport of spilled oil and, ultimately, the socioeconomic impacts of a spill. For example, winds and currents may carry spilled oil toward coastal population centers (resulting in significant impacts) or out to sea (resulting in less significant impacts). Between these two variables, there are an infinite number of permutations for conditions at the time of a spill. Although the analysis of spill-related socioeconomic impacts presented in this report reflects a discrete set of conditions for currents and wind, the conditions chosen for this analysis are based on probabilistic oil spill modeling covering a variety of potential conditions. This probabilistic (or stochastic) modeling was conducted both to inform and complement the assessment of spill-related socioeconomic impacts.

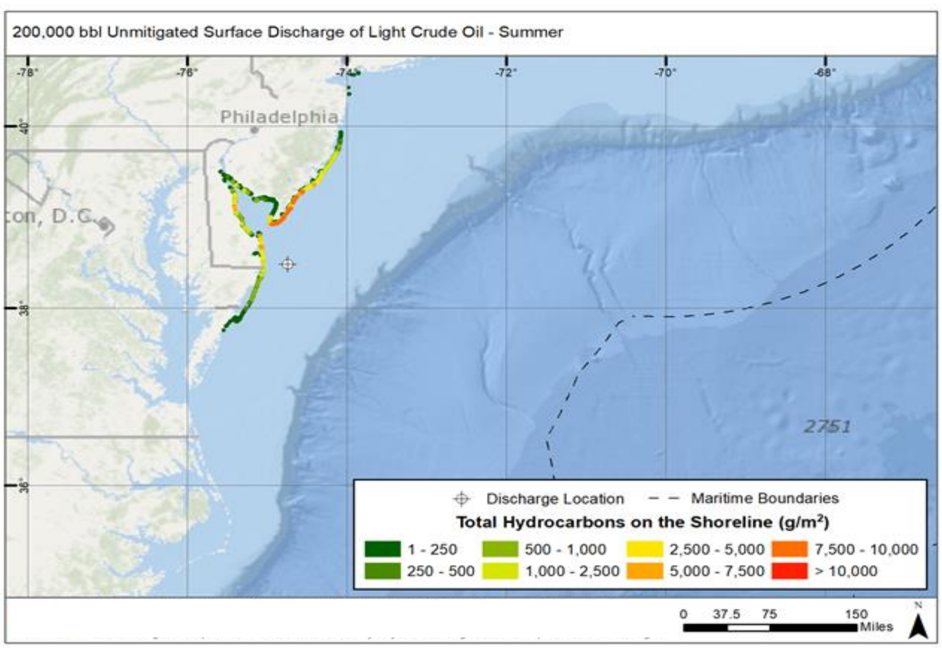
The probabilistic modeling involves simulations of multiple spill trajectories, each representing a different set of conditions at the time of and immediately following a spill. To capture natural variation in conditions, each simulation in the probabilistic analysis is based on conditions observed during a randomly selected calendar date between 1 April 2018 and 20 April 2020. Because conditions are often dependent on the season and because the socioeconomic impacts of oiling are also dependent on the season, the probabilistic modeling was conducted on a seasonal basis.[15] Thus, for each combination of spill location and spill size, one set of probabilistic runs is based on winds and currents observed on historical days in the summer, another set is based on conditions observed during fall days, etc.

After the probabilistic modeling was complete, the "worst case" (deterministic) spill event from each set of stochastic runs was chosen for the assessment of socioeconomic impacts. The identification of worst-case exposure conditions for a given spill size and location was based on the maximum length of shoreline oiled (with an oil concentration

[15] For the purposes of defining seasons, winter is December through February; spring is March through May; summer is June through August; and fall is September through November.

>1.0 g/m^2) among the stochastic simulations. For example, Exhibit 2-3 shows the worst - case shoreline oiling for the 200,000 bbl spill simulations for the spill site just outside Delaware Bay. Because the geographic scope of the oil spill modeling covers the broader Mid-Atlantic region, the worst-case scenario is based on the maximum shoreline oiled *across the entire region*. For a limited number of scenarios, the conditions that result in the maximum length of shoreline oiled for the region may not be the same conditions that result in the maximum amount of shoreline oiling for Delaware. This reflects the possibility that conditions leading to significant shoreline oiling north or south of Delaware may not necessarily result in significant oiling of Delaware's shoreline. However, because one of DNREC's objectives for this study is to improve understanding of worst-case spills regardless of the area(s) affected, the focus on maximum shoreline oiling for the region, rather than just for Delaware, provides policymakers and the public with useful information consistent with this objective.[16] In addition, while shoreline oiling is a reasonable metric for identifying worst-case conditions, some of the socioeconomic impacts examined in this report are not based on shoreline oiling but are instead based on the area of the oil sheen on the surface of the water. The worst-case chosen from the probabilistic (stochastic) simulations therefore may not capture the worst-case for these categories of impact. While it would have been possible to define worst case spills for individual categories of impact, doing so would have led to inconsistencies across impact categories and complicated comparisons of impacts across categories, because the impact estimates for different activities would, in effect, reflect different spills. Avoiding such inconsistencies requires the specification of a worst-case applied across all impact categories.

EXHIBIT 2-3. WORST CASE SHORELINE OILING FOR 200,000 BARREL (BBL) SPILL SIMULATIONS FOR THE NEARSHORE DELAWARE SITE



16 For a limited number of spill scenarios where reliance on the worse case for the region leads to counterintuitive impact estimates, this report includes a sensitivity analysis examining worst case impacts for Delaware rather than for the broader mid-Atlantic region.

Based on the information above regarding the selection of the worst-case conditions and the variables for defining individual spills, Exhibits 2-4 through 2-6 summarize each of the spill scenarios analyzed. Each exhibit includes the simulated spills off a given state's coast. For each state, 20 distinct spill scenarios are analyzed: four low-volume surface spills (all unmitigated), four medium-volume surface spills (all unmitigated), four subsurface blowout scenarios (all unmitigated), and eight high-volume surface spills (four mitigated and four unmitigated).

OIL SPILL MODELING METHODS

This analysis applies the SIMAP modeling system to simulate the fate and transport of spilled oil. SIMAP, as documented in French-McCay (2003, 2004) and French-McCay et al. (2018b) quantifies oil trajectory, concentrations of oil hydrocarbon components as droplet and dissolved phases in the water column, areas swept by floating oil of varying mass concentrations and thicknesses, shorelines oiled to varying degrees, and amount of oil settling to sediments. Processes simulated by SIMAP include spreading (gravitational and by currents shearing oil apart), evaporation of volatile oil components from surface oil, transport on the surface and in the water column, turbulent diffusion (random movements from small-scale motions, i.e., mixing), emulsification (incorporation of water droplets into the oil to form mousse), entrainment of oil as droplets into the water column due to waves (either without or facilitated by dispersant application), dissolution of soluble and semi-soluble hydrocarbon (S/SS-HC) components, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended particulate matter, adsorption of semi-soluble hydrocarbons to suspended particulate matter, sedimentation, stranding on shorelines, and degradation (based on component-specific biodegradation and photo-oxidation rates). The model tracks soluble and semi-soluble components of the oil (i.e., monoaromatic hydrocarbons [MAHs, such as benzene, toluene, ethylbenzene and xylene, BTEX], polycyclic aromatic hydrocarbons [PAHs], and soluble alkanes; i.e., S/SS-HCs), as well as insoluble volatile aliphatic hydrocarbons, separately from high-molecular weight non-volatile and insoluble components of the oil. These components are modeled in groups of hydrocarbons with similar physical-chemical properties, termed pseudo-components. Sublots of the discharged oil are represented by Lagrangian Elements ("spillets"), each characterized by location, physical state (floating, droplet in water, sedimented, ashore), mass of the various hydrocarbon components, water content, thickness, diameter, density, viscosity, and associated suspended particulate matter mass. A separate set of Lagrangian Elements is used to track mass and movements of the dissolved hydrocarbons. A detailed description of the model algorithms and assumptions is in French-McCay et al. (2018b). The floating oil entrainment model is also described in detail in Li et al. (2017).

The SIMAP model has been validated with data from more than 20 large oil spills, including the *Exxon Valdez*, *North Cape* and *Deepwater Horizon* oil spills (French and Rines 1997; French-McCay 2003, 2004; French-McCay and Rowe 2004; French-McCay et al. 2015, 2016, 2018a,b), as well as test spills designed to verify the model (French et al. 1997). These studies showed that oil trajectories depended primarily on the current and wind data input to the model.

EXHIBIT 2-4. OIL SPILL SCENARIOS FOR SPILLS OFF DELAWARE'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
DE-1	Offshore Delaware	Surface Unmitigated 126 bbl Release During Winter	Low	2/28/2019
DE-2		Surface Unmitigated 126 bbl Release During Spring	Low	5/25/2018
DE-3		Surface Unmitigated 126 bbl Release During Summer	Low	6/25/2018
DE-4		Surface Unmitigated 126 bbl Release During Fall	Low	10/3/2019
DE-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	2/28/2019
DE-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	5/15/2018
DE-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	6/25/2018
DE-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	10/1/2019
DE-9		Surface Unmitigated 200k bbl Release During Winter	High	2/28/2019
DE-10		Surface Unmitigated 200k bbl Release During Spring	High	5/15/2019
DE-11		Surface Unmitigated 200k bbl Release During Summer	High	6/25/2018
DE-12		Surface Unmitigated 200k bbl Release During Fall	High	10/1/2019
DE-13		Surface Mitigated 200k bbl Release During Winter	High	2/28/2019
DE-14		Surface Mitigated 200k bbl Release During Spring	High	5/15/2019
DE-15		Surface Mitigated 200k bbl Release During Summer	High	6/25/2018
DE-16		Surface Mitigated 200k bbl Release During Fall	High	10/1/2019
DE-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
DE-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/26/2018
DE-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	6/2/2018
DE-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

EXHIBIT 2-5. OIL SPILL SCENARIOS FOR SPILLS OFF NEW JERSEY'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
NJ-1	Offshore New Jersey	Surface Unmitigated 126 bbl Release During Winter	Low	12/7/2018
NJ-2		Surface Unmitigated 126 bbl Release During Spring	Low	5/1/2018
NJ-3		Surface Unmitigated 126 bbl Release During Summer	Low	8/28/2019
NJ-4		Surface Unmitigated 126 bbl Release During Fall	Low	9/28/2019
NJ-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	12/7/2018
NJ-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	5/1/2018
NJ-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	8/28/2019
NJ-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/28/2019
NJ-9		Surface Unmitigated 200k bbl Release During Winter	High	12/7/2018
NJ-10		Surface Unmitigated 200k bbl Release During Spring	High	5/1/2018
NJ-11		Surface Unmitigated 200k bbl Release During Summer	High	8/28/2019
NJ-12		Surface Unmitigated 200k bbl Release During Fall	High	9/27/2019
NJ-13		Surface Mitigated 200k bbl Release During Winter	High	12/7/2018
NJ-14		Surface Mitigated 200k bbl Release During Spring	High	5/1/2018
NJ-15		Surface Mitigated 200k bbl Release During Summer	High	8/28/2019
NJ-16		Surface Mitigated 200k bbl Release During Fall	High	9/27/2019
NJ-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
NJ-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/21/2018
NJ-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	8/9/2019
NJ-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

EXHIBIT 2-6. OIL SPILL SCENARIOS FOR SPILLS OFF VIRGINIA'S COAST

SCENARIO ID	SPILL SITE	SPILL EVENT	SPILL VOLUME	START DATE OF WORST CASE
VA-1	Offshore Virginia	Surface Unmitigated 126 bbl Release During Winter	Low	1/13/2020
VA-2		Surface Unmitigated 126 bbl Release During Spring	Low	3/9/2020
VA-3		Surface Unmitigated 126 bbl Release During Summer	Low	6/19/2018
VA-4		Surface Unmitigated 126 bbl Release During Fall	Low	10/13/2019
VA-5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	1/13/2020
VA-6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	3/9/2020
VA-7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	7/19/2018
VA-8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/21/2019
VA-9		Surface Unmitigated 200k bbl Release During Winter	High	1/13/2020
VA-10		Surface Unmitigated 200k bbl Release During Spring	High	5/28/2018
VA-11		Surface Unmitigated 200k bbl Release During Summer	High	7/19/2018
VA-12		Surface Unmitigated 200k bbl Release During Fall	High	9/21/2019
VA-13		Surface Mitigated 200k bbl Release During Winter	High	1/13/2020
VA-14		Surface Mitigated 200k bbl Release During Spring	High	5/28/2018
VA-15		Surface Mitigated 200k bbl Release During Summer	High	7/19/2018
VA-16		Surface Mitigated 200k bbl Release During Fall	High	9/21/2019
VA-17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/21/2019
VA-18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/13/2018
VA-19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	8/25/2019
VA-20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2019

OIL SPILL MODELLING OUTPUTS

The oil spill modeling results include two key outputs used for the analysis of socioeconomic impacts: (1) length of shoreline with oil exposure exceeding thresholds of concern and (2) area of floating surface oil exceeding thresholds of concern. As described in the chapters that follow, this analysis uses the former for the assessment of beach recreation, and recreational fishing impacts and the latter for the assessment of impacts to commercial fishing, recreational boating, response costs and shipping. Thresholds of concern were reviewed by French-McCay (2009, 2016) and French-McCay et al. (2018a), based in part on work described in French-McCay (2002, 2003, 2004). Thresholds are generally expressed as an area-based concentration or loading (grams per meter squared [g/m^2]; 1 g/m^2 is approximately 1 micrometer (μm) thick oil, on average, if the oil is not emulsified or up to approximately 6 μm thick if emulsified) of floating or shoreline oil that could potentially adversely affect a resource (French-McCay 2009; French-McCay 2016). Based on the review studies cited above and in accordance with current practice in oil spill risk assessments, the following thresholds of concern are applied:

- **Floating Surface Oil Thickness Thresholds: ≥0.01 g/m^2 (~0.01 μm thick on average over an area)**
  - Oil sheens at the minimum concentration of 0.01 g/m^2 are just barely visible (National Oceanic and Atmospheric Administration's (NOAA) 2016; Bonn 2009, 2011).
  - Effects on socioeconomic resources may occur (e.g., fishing may be prohibited) if oil is visible on the water surface, i.e., ≥0.1 g/m^2. This threshold is used for the socioeconomic impact categories affected by surface water oiling.
- **Shoreline Thickness Thresholds: ≥1 g/m^2 (~1 μm thick on average over an area)**
  - The threshold of 1 g/m^2 represents an oil amount that would appear as a dull brown color.
  - Effects on socioeconomic resources may occur (e.g., reduced beach use) above a threshold of 1 g/m^2.

CHAPTER 3 | RECREATION

This chapter presents the analysis of impacts to marine and coastal recreation in Delaware resulting from each of the oil spill scenarios described in Chapter 2. The categories of recreation considered include beach use, recreational fishing, and recreational boating. For each form of recreation, the analysis presents the spill-related reduction in recreational activity and the economic welfare loss associated with such reductions.[17] The latter is defined as the value that individual users derive from pursuing an outdoor recreation activity, net of the costs of doing so. Although reductions in recreational activity may also affect employment, GDP, and household income within Delaware, these effects are analyzed separately in Chapter 7.

OVERVIEW

For each category of recreation, this analysis begins with specification of baseline levels of use in each season, measured in user days. Because there is potential for double counting between recreation categories, the baseline use for each category is defined so as to minimize the potential for double counting. For example, baseline use for recreational fishing is restricted to fishing activity in non-beach areas since beach-based fishing is likely reflected in beach use statistics. Similarly, because fishing on charter boats or party boats is captured in the recreational boating category, recreational fishing in this analysis is restricted to exclude boat-based fishing. For all three categories of recreation, the seasonal estimates of activity for Delaware are spatially distributed to different zones within Delaware's coastal and marine environments.

To estimate the reduction in use for each spill scenario and recreational activity, this analysis examines the spatial overlap between the recreation zones for each activity and potential oiling under each of the modeled spill scenarios. In areas where oiling occurs under a given scenario, the estimated reduction in recreational activity reflects either use reductions following similarly sized spills in the past or the duration of area closures (e.g., beach closures) associated with past spill events. Following this approach, the number of lost user days may vary by season even among scenarios with similar amounts of oiling. This is due to differences in the intensity of coastal and marine recreation during the course of the year. To assess the economic value of reductions in recreational activity, this analysis applies estimates of the value per recreational user day obtained from the literature.

[17] Throughout this chapter, the economic value of the losses experienced by recreators are referred to interchangeably as welfare losses, welfare effects, and consumer surplus losses.

The following sections detail the data and methods applied in the analysis, separately for beach use, recreational fishing, and recreational boating.

BEACH USE

This section outlines the analytical methodology for estimating the lost recreational value associated with reductions in beach use resulting from the spill scenarios described in Chapter 2. The analysis of these impacts begins with specification of baseline beach use, followed by estimation of spill-related reductions in beach use and the value of these reductions.

BASELINE BEACH USE

To estimate the magnitude of potential spill-related changes in beach use, this analysis begins with the specification of baseline visitor activity at Delaware's beaches. This baseline is defined for six groups of beaches as shown in Exhibit 3-1. As indicated in the exhibit, the beach groups include a single group for beaches on Delaware Bay and five groups for beaches on Delaware's Atlantic coast. Disaggregating statewide beach visitation to these individual groups allows the analysis to account for the possibility that a given spill may lead to oiling for only a portion of Delaware's coastline.

EXHIBIT 3-1. DELAWARE BEACH GROUPINGS, ORDERED NORTH TO SOUTH

GROUP NAME	COASTLINE	INCLUDED BEACHES
Bay Beaches	Delaware Bay	Pickering, Kitts Hummock, Bowers, Slaughter, Prime Hook, Broadkill, Lewes
Cape Henlopen State Park	Atlantic	Cape Henlopen State Park
Rehoboth Area	Atlantic	North Shores, Henlopen Acres, Rehoboth
Dewey Area	Atlantic	Dewey
Central Atlantic Coastline	Atlantic	Indian, Delaware Seashores State Park, North Bethany
South Atlantic Coastline	Atlantic	Bethany, Sea Colony, South Bethany, Fenwick Island State Park, Fenwick Island

For each beach group, annual use estimates were derived from survey data compiled by research teams led by Dr. George Parsons of the University of Delaware. For the Delaware Bay beaches, this analysis relies upon beach use data from Parsons (2013).[18] For beaches on the Atlantic coast, data compiled for Parsons and Firestone (2018) serve as the foundation for the beach use estimates. The aggregate beach use estimates from Parsons and Firestone (2018) for Delaware's Atlantic beaches are allocated to the beach groups in Exhibit 3-1 based on the spatial distribution of beach use from University of

[18] Lewes Beach was not captured in the Parsons (2013) data, but it is included it here using an average of seasonal user days measured at North Shores and Henlopen Acres. While these beaches are located on the Atlantic coastline, consultation with Dr. George Parsons at the University of Delaware confirmed that they have similar levels and distribution of visitation days as Lewes Beach.

Delaware (2005). Because beach activity varies by season, the annual estimates of beach activity are distributed across seasons. The Delaware Bay beach data compiled for Parsons (2013) is expressed by season already. For the beach groups located along the Atlantic coastline, however, the data are reported as annual values. These values were distributed across seasons for this analysis based on distributional data for the Delaware Bay beaches, Dewey Beach, and select National Seashores along the Mid-Atlantic and Northeast U.S. coasts. Specifically, the distribution for Delaware's Atlantic beaches was calculated by averaging (1) the combined distribution associated with Dewey Beach and the Delaware Bay beaches and (2) the average of the distributions for the Cape Cod, Assateague Island, and Cape Hatteras National Seashores.[19] The following equation summarizes the derivation of the monthly distribution:

$$Atlantic\ Monthly\ Share_t = \frac{BD_t + NS_t}{2}$$

Where:

Atlantic Monthly Share$_t$ = the estimated share of total beach visitation for each month (t).

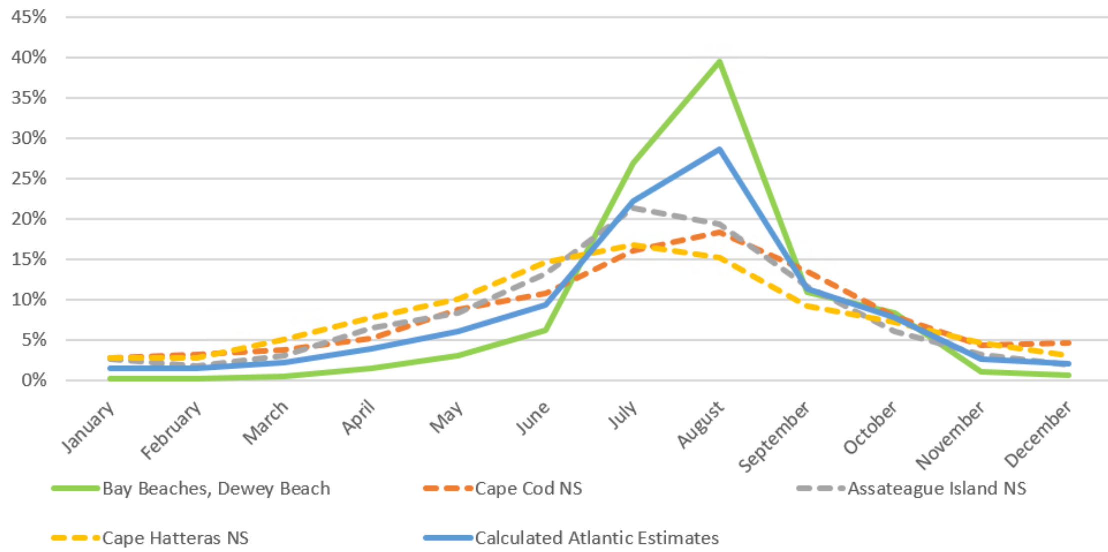
BD_t = the combined monthly share of the Bay beaches and Dewey Beach, weighted by total visitation, for each month (t).

NS_t = the combined monthly share of visitation for Cape Hatteras National Seashore, Cape Cod National Seashore, and Assateague Island National Seashore, for each month (t).

As noted above, the analysis depends, in part, on the temporal distribution of beach use at Dewey Beach to calculate a distribution for Delaware's Atlantic beaches more broadly. The analysis does not rely on the Dewey Beach distribution alone due to input provided by the Delaware Department of Natural Resources and Environmental Control (DNREC) indicating that visitors to Dewey Beach may not be representative of the typical visitors to Delaware's Atlantic beaches. Specifically, DNREC indicated that Dewey Beach is a popular beach for individuals in their late teens and early twenties but not as popular for families with children and older beachgoers. To ensure that the seasonal distribution applied to the Atlantic beaches is representative of all demographic groups, the Dewey Beach data were combined with the other sources identified above. Exhibit 3-2 below shows the monthly share distribution for each of the sources used in the distributional calculation, as well as the resulting distribution used in this analysis.

[19] The distribution for the Delaware Bay beaches is from Parsons et al. (2013). The distribution for Dewey Beach is from Rehoboth Beach-Dewey Beach Chamber of Commerce (2016). The distributions for select National Seashores are from U.S. National Park Service (2020).

EXHIBIT 3-2. TEMPORAL DISTRIBUTION, BAY BEACHES AND CALCULATED ATLANTIC BEACH ESTIMATES



For the purposes of estimating spill-related damages, the monthly data represented in Exhibit 3-2 are integrated with annual beach use data to generate beach use estimates by season, with winter including December through February, spring including March through May, summer including June through August, and fall including September through November. The resulting estimates for baseline beach use by season and beach group are presented in Exhibit 3-3.

EXHIBIT 3-3. DELAWARE BEACH BASELINE USER DAYS BY SEASON

BEACH GROUP	WINTER	SPRING	SUMMER	FALL	SHARE OF TOTAL
Bay Beaches	4,842	20,522	81,774	28,455	1.19%
Cape Henlopen State Park	30,344	73,289	355,051	129,208	5.14%
Rehoboth Area	116,318	280,939	1,361,029	495,297	19.72%
Dewey Area	44,251	106,879	517,783	188,428	7.50%
Central Atlantic Coastline	108,732	262,617	1,272,266	462,995	18.43%
South Atlantic Coastline	283,209	684,027	3,313,810	1,205,941	48.01%
Total	587,696	1,428,273	6,901,714	2,510,325	**Total: 11,428,008**
Share of Total	5.14%	12.50%	60.39%	21.97%	

ESTIMATION OF BEACH USER DAYS LOST

The estimated number of lost user days for each season-specific, worst-case spill scenario is based upon the spatial intersection of shoreline oiling and the individual beach groups listed above in Exhibit 3-1. The following equation summarizes the approach for estimating the number of beach user days los for each scenario:

$$Beach_s = \sum_{b,t} \left(B_{b,t} \times L_{s,b} \times R_{s,b,t} \right)$$

Where:

$Beach_s$ = the estimated number of beach user days lost for each oil spill scenario (s),

$B_{b,t}$ = the baseline number of beach user days for each beach group (b) and season (t) during which beach use is affected by a spill;

$L_{s,b}$ = a binary indicator of whether each beach group (b) is oiled under each spill scenario (s), and

$R_{s,b,t}$ = for each oil spill scenario (s), the percent reduction in beach use in each season (t) in the event that a given beach group (b) is oiled as a result of the spill (i.e., if $L_{s,b}$=1).

As indicted by the above equation, the reduction in beach use is estimated by beach group and for a number of seasons after a hypothetical spill occurs. These reductions are summed across beach groups and seasons to arrive at the total estimate of reduced beach use (i.e., lost user days). Each of the analytic elements shown in the equation is described further below.

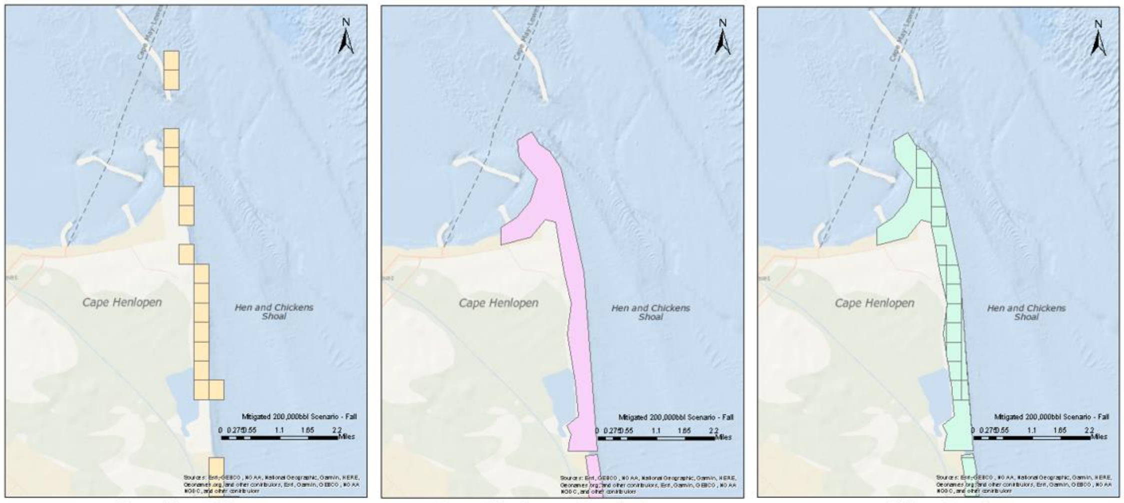
Baseline Level of Beach Use Activity

This value encompasses the baseline number of beach user days for each beach group for each season affected by a spill. The development of these estimates is described in the "Baseline Beach Use" section above. Because beach use varies by season, the baseline beach use potentially affected by a spill of a given size varies over the course of the year. For instance, a 900,000 barrel spill occurring in the fall will see the bulk of its effects in the lower traffic fall, winter, and spring seasons, while the same modeled spill occurring in the summer will affect a much larger share of annual beach user days for affected beaches.

Indicator of Oiling by Beach Group ($L_{s,b}$)

To identify the beach groups affected by shoreline oiling under each scenario, this analysis relied upon a GIS spatial overlay of modeled shoreline oiling for each oil spill scenario on the beach groups identified above. For each spill scenario, the GIS analysis projected oiling along the beach for a series of grid cells approximately 400 meters in length. A given shoreline grid cell was considered oiled above a threshold of concern if the oil concentration in that grid cell exceeded the threshold value of 1 g/m^2 identified in Chapter 2. If at least one grid cell within a beach group's boundary was oiled above this threshold, the value of $L_{s,b}$ was set equal to 1 for that beach group, signifying that beach use for the entire beach group would be affected by the spill. While this assumption may be conservative when oiling is projected for only some shoreline grid cells in a beach group, recreators may avoid all beaches in a beach group if oiling is observed at any nearby beaches. Exhibit 3-4 shows an example of the overlay analysis for shoreline oiling within the Cape Henlopen beach group. The first panel of the exhibit shows the gridded areas along the coast with shoreline oiling in excess of 1 g/m^2, and the second panel shows the boundaries for the Cape Henlopen beach group. Because oiling above the threshold of concern is projected for many (though not all) of the grid cells within the beach group boundary, beach use for the entire beach group is assumed to be affected by the spill, as shown in the third panel in the exhibit.

EXHIBIT 3-4. BEACH USE OILING OVERLAP, CAPE HENLOPEN BEACH GROUP



Shoreline Oiling | Cape Henlopen Beach Group | Oiling Overlap

Percent Reduction in Beach Use ($R_{s,b,t}$)

For beach group with oiling in excess of the threshold of concern, this analysis applies assumptions regarding the percentage reduction in use derived from past spill events. The assumed reductions in some cases reflect the percent reduction in use observed following past spills and in other cases reflect the duration of beach closures following past spills. The assumptions applied in the analysis are unique to each spill size. For the two smallest spill size categories (126 barrels and 2,240 barrels), the assumed reductions in use are restricted to the season in which the spill occurs. Based on beach closures following the 9,900-barrel American Trader oil spill, this analysis assumes a 21-day closure for the 2,240-barrel spill scenarios.[20] Assuming a uniform distribution of use across the season, this translates to a 23 percent reduction in use. Limited information on closure durations is available for spills similar in magnitude to the 126-barrel spill scenarios. In the absence of such information, this analysis assumes a 10-day beach closure (approximately half the duration of the 2,240-barrel scenarios), when the 126-barrel spill scenarios result in oiling above the threshold of concern. This translates to an 11 percent reduction in use for the season.

For the two largest spill sizes modeled, the assumed percentage reduction in beach use extends beyond one season. Drawing on the experience of the *Deepwater Horizon* spill, this analysis assumes that the 900,000-barrel subsurface blowout scenario results in reductions in use for up to 18 months, or six seasons. According to the lost recreational use assessment conducted after the *Deepwater Horizon* spill, beach use in the northern Gulf of Mexico, where beach oiling was more significant, declined by 45 percent during the nine-month period (i.e., three seasons) after the spill and by 10 percent for the 10 months (i.e., approximately three seasons) after that. On the Florida Peninsula, beach use

[20] See Chapman and Hanemann (2001).

declined by approximately 22 percent during the nine months immediately after the spill (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). Applying these findings to a potential 900,000-barrel blowout event in the Mid-Atlantic, this analysis assumes that oiled beach groups would follow a similar pattern as northern Gulf of Mexico beaches and that beach groups not oiled would follow a pattern similar to beaches on the Florida Peninsula. In other words, oiled beach groups would see a 45 percent reduction in use for three seasons followed by a 10 percent reduction for an additional three seasons, and beach groups not oiled would experience a 22 percent reduction limited to the nine months (three seasons) following the spill event.

Exhibit 3-5 shows the proportional change in use for each spill scenario and season, based on the explanation above. The darker shading of red in a given cell in the exhibit indicates a more significant reduction in use, and lighter shading indicates a less significant use reduction.

EXHIBIT 3-5. REDUCTION ASSUMPTIONS BY SPILL SIZE, BEACH USE AND RECREATIONAL FISHING

Recreation Category	Spill Type	Spill Scenario	Percent Use Reduction (seasons following spill)						Assumptions
			Season 1	Season 2	Season 3	Season 4	Season 5	Season 6	
Beach Use, Fishing	Surface	Unmitigated 200,000bbl	35.7%	12.7%	12.7%	12.7%	3.8%	3.8%	12.7% reduction for Seasons 1-4, 3.8% for Seasons 5-6*
	Surface	Mitigated 200,000bbl	35.7%	12.7%	12.7%	12.7%	3.8%	3.8%	12.7% reduction for Seasons 1-4, 3.8% for Seasons 5-6*
	Surface	Unmitigated 2,240bbl	23.0%	0.0%	0.0%	0.0%	0.0%	0.0%	21-day closure in Season 1**
	Surface	Unmitigated 126bbl (surface)	11.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10-day closure in Season 1***
	Subsurface	Unmitigated 900,000bbl (oiled zones)	45.2%	45.2%	45.2%	10.0%	10.0%	10.0%	45% use reduction for Seasons 1-3, 10% for
	Subsurface	Unmitigated 900,000bbl (not oiled zones)	22.2%	22.2%	22.2%	0.0%	0.0%	0.0%	22% use reduction for non-oiled zones****

* Based on use reductions following the Exxon Valdez oil spill off the coast of Alaska, 1992.
** Based on use reductions following the American Trader oil spill in Southern California, 1990.
*** An assumed reduced closure length based on the smaller spill size relative to the 2,240bbl scenarios.
**** Based on use reductions following the Deepwater Horizon oil spill in the Gulf of Mexico, 2010.

For the 200,000-barrel surface spill scenarios, beach use information for comparable spills is unavailable. In the absence of such information, assumptions for the 200,000-barrel scenarios are based on a combination of the assumed reduction in beach use for the 2,240-barrel spill scenarios and measured changes in sport fishing activity along the southern coast of Alaska following the 1992 *Exxon Valdez* spill, as presented in Mills (1992). As noted above, this analysis assumes a 21-day closure for 2,240-barrel spills. Because a 200,000-barrel spill is likely to result in impacts at least as significant as a 2,240-barrel spill occurring in identical conditions, this analysis assumes that a 21-day closure would apply to beaches oiled by 200,000-barrel spills as well. To capture reductions in beach use beyond this 21-day period, this analysis assumes that the proportional reduction in sport fishing activity following the *Exxon Valdez* spill is a reasonable indicator of the reduction in use beyond initial beach closures. Based on Mills (1992), this translates to a 12.7 percent reduction in use for the full year following the spill (four seasons in total) and a 3.8 percent reduction for the first six months of the following year (two additional seasons, for six in total). Because the data for the *Exxon*

Valdez spill do not reflect the more immediate effects of a beach closure, the 12.7 percent reduction occurring in season 1 (the season of a spill) is assumed to be additive with the reduction in use associated with the assumed 21-day beach closure.

ESTIMATED VALUE PER LOST BEACH DAY

To estimate the economic value of the lost beach recreation days associated with the shoreline oiling projected for a given spill scenario, this analysis applies consumer surplus values per user day for Rehoboth Beach derived from Efimova (2019). This study includes consumer surplus estimates for single day beach trips to Rehoboth Beach, short overnight trips, and long overnight trips.[21] The average consumer surplus per user day was estimated for each of these trip types by dividing the value per trip by the average duration of each trip type. The average consumer surplus value per user day was then calculated as the weighted average of these values, using the number of user days included in Efimova (2019) for each trip type as weights. After adjusting for inflation, this yields an estimate of $42.14 per lost beach use day. While the consumer surplus values in Efimova (2019) are specific to Rehoboth Beach, this analysis applies them to all beach recreation in Delaware, under the assumption that Rehoboth Beach is representative of beach use across the state.

RESULTS

Applying the data and methods described above, the estimated reductions in beach user days for each oil spill scenario are presented in Exhibit 3-6. The corresponding reductions in consumer surplus are shown in Exhibit 3-7. Consistent with the focus of this study, all estimated effects are to beach use in Delaware, even for the spill locations off the coasts of New Jersey and Virginia. The red bars in Exhibits 3-6 and 3-7 show the relative magnitude of impacts across spill scenarios (i.e., the red bar for the highest-impact scenario fills an entire cell in the exhibit, and red bars for other cells are proportionately smaller based on the estimated impacts).

As shown in Exhibits 3-6 and 3-7, the estimated welfare losses related to beach use tend to be highest when a spill occurs during the summer. This is due to both higher beach use in the summer and ocean current and wind patterns resulting in greater shoreline oiling during the summer spill scenarios. For the blowout spill scenarios, however, the effects are more pronounced when the spill occurs in the spring than in the summer. This result reflects the long duration of effects associated with the blowout scenarios. As indicated in Exhibit 3-5 above, this analysis (drawing from the experience of the *Deepwater Horizon* spill) assumes that beaches oiled following a 900,000-barrel well blowout experience a 45 percent reduction in use over three seasons. Thus, when these spills occur in the spring, they have significant effects for the highest use seasons—spring, summer, and fall. In contrast, a blowout occurring in the summer leads to 45 percent reductions to oiled beaches in the summer, fall, and winter.

[21] As presented in Efimova (2019), the averages were 1 day per trip for single day beach trips, 2.6 days per trip for short overnight trips, and 6.2 days per trip for long overnight trips.

Exhibit 3-6 and 3-7 also show that beach use impacts are most significant for the spill scenarios off the coast of Delaware. This reflects the greater extent of shoreline oiling along Delaware's coast for spills that occur in close proximity to Delaware. In addition, for some of the New Jersey and Virginia spill scenarios, the results show no impact, such as the winter season surface spills off the Delaware coast. Under these scenarios, oil is not projected to reach the Delaware coastline based on the oil spill modeling described in Chapter 2.

EXHIBIT 3-6. LOST BEACH USER DAYS DUE TO OILING, WORST CASE SPILL SCENARIOS

Worst Case Lost User Days due to Oiling - Beach Use						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	157,000	756,000	132,000	-
	Surface	Unmitigated 2,240bbl	329,000	1,588,000	571,000	-
	Surface	Unmitigated 200,000bbl	2,097,000	3,398,000	2,122,000	-
	Surface	Mitigated 200,000bbl	1,964,000	3,398,000	2,122,000	-
	Subsurface	Unmitigated 900,000bbl	5,792,000	5,604,000	3,046,000	3,861,000
New Jersey	Surface	Unmitigated 126bbl	-	756,000	-	-
	Surface	Unmitigated 2,240bbl	-	1,588,000	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	5,792,000	5,604,000	3,046,000	4,483,000
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	2,258,000	-	-
	Subsurface	Unmitigated 900,000bbl	5,751,000	2,220,000	1,005,000	1,980,000

EXHIBIT 3-7. WELFARE LOSSES DUE TO REDUCED BEACH USE, WORST CASE SPILL SCENARIOS

Worst Case Lost Use Value due to Oiling - Beach Use						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$ 6,600,000	$ 31,900,000	$ 5,600,000	$ -
	Surface	Unmitigated 2,240bbl	$ 13,900,000	$ 66,900,000	$ 24,100,000	$ -
	Surface	Unmitigated 200,000bbl	$ 88,400,000	$143,200,000	$ 89,400,000	$ -
	Surface	Mitigated 200,000bbl	$ 82,700,000	$143,200,000	$ 89,400,000	$ -
	Subsurface	Unmitigated 900,000bbl	$244,000,000	$236,100,000	$128,300,000	$162,700,000
New Jersey	Surface	Unmitigated 126bbl	$ -	$ 31,900,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 66,900,000	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ -	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$244,000,000	$236,100,000	$128,300,000	$188,900,000
Virginia	Surface	Unmitigated 126bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ 95,200,000	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$242,300,000	$ 93,500,000	$ 42,300,000	$ 83,400,000

As expected, the larger spill sizes in a given location generally result in more significant beach use impacts than smaller spills. This is due to more widespread shoreline oiling under these scenarios as well as the extended, multi-season use reduction effects associated with larger spills. One exception to this pattern, however, is the surface spills occurring during the summer off the coast of New Jersey. As shown in Exhibits 3-6 and 3-7, this analysis projects Delaware beach use impacts for the 126- and 2,240-barrel spills but not the 200,000-barrel spills. This reflects how the worst-case spill is defined for each scenario. As described in Chapter 2, the specification for the worst-case scenario is based on the maximum shoreline oiled *across the entire Mid-Atlantic region* rather than the maximum shoreline oiling on Delaware's coast. In the case of the 200,000-barrel summer spill off the coast of New Jersey, the maximum shoreline oiling is projected when currents and the wind carry the oil northward, causing significant oiling along the coast of New Jersey and the southern coast of Long Island, but no oiling to Delaware's coast. As a sensitivity analysis, the appendix to this report presents recreational impacts under an alternative specification of the 200,000-barrel summer spills off the coast of New Jersey, using the same conditions as assumed for the 126- and 2,240-barrel worst-case spills, which shows higher impacts to Delaware than the results presented here.

The results in Exhibits 3-6 and 3-7 also indicate that the subsurface blowout scenarios always have some impact on beach use even if oiling does not reach the shore, due to the assumption based on the *Deepwater Horizon* spill that a catastrophic blowout will result in some decreased beach use over the broader region for an extended period. As an example, this can be seen in the fall and winter spill scenarios for Virginia, under which the Delaware coastline experiences no oiling. Based on the reductions in beach use observed following the *Deepwater Horizon* spill for beaches in the Gulf of Mexico that were not oiled, some beachgoers are likely to stay away from beaches across the broader region in which a major well blowout occurs.

Comparing the results for the unmitigated and mitigated 200,000-barrel scenarios, mitigation is projected to have minimal impact in reducing beach use losses in Delaware when the spill location is off the coast of Delaware but is projected to have greater effectiveness for reducing losses (to Delaware) for spills off the coast of Virginia. These results are consistent with the oil spill modeling summarized in Chapter 2 and described in detail in RPS (2020). Although mitigation is projected to reduce the overall length of shoreline oiled, these reductions are more significant for sites located farther from a spill than sites in closer proximity to a spill.

RECREATIONAL FISHING

In addition to impacting beach use, shoreline oiling may also lead to welfare losses associated with recreational fishing activity along Delaware's coast. This section presents an assessment of these impacts for each of the oil spill scenarios summarized in Chapter 2. As described below, the analysis begins with the specification of baseline recreational fishing activity in Delaware, followed by estimation of spill-related reductions in activity and the corresponding welfare losses to recreational anglers.

BASELINE RECREATIONAL FISHING ACTIVITY

To estimate baseline recreational fishing activity, this analysis relies on data from NOAA's Marine Recreational Information Program (MRIP). The MRIP data files contain information on total annual user days, a database of known fishing sites in the state of Delaware, and pressure data for a set of 69 fishing sites across the state by two-month "wave" collected through in-person surveys that measure fishing activity level and mode.

For the purposes of this analysis, all fishing occurring on recreational beaches and on charter or party boats is excluded to avoid double counting with beach use and recreational boating.

This analysis uses the 2019 MRIP data for the statewide total number of recreational fishing user days and applies county-level data from the 2016 version of the MRIP data to determine the breakdown by county. Due to changes in the way MRIP provides its recreational fishing user day totals, 2016 is the most recent year for which geographic information below the statewide level is available for Delaware. Because Delaware has only three counties, with Sussex County taking up the largest share of its coastline and all of its Atlantic-facing coastline, Sussex County was split into two categories for this analysis, one category for fishing on the Delaware Bay (Sussex-Bay) and one for fishing on the Atlantic (Sussex-Atlantic). Fishing days were distributed between these two portions of the county by using the relevant pressure data at the MRIP fishing sites in each category. For the purposes of this report, the resulting categories (New Castle County, Kent County, Sussex County (Bay), and Sussex County (Atlantic)) are referred to as the "fishing counties."

MRIP recreational fishing data are collected in two-month "waves." For example, wave 2 includes February and March. The 2019 fishing day totals data do not include wave 1, so 2016 MRIP data were used to add additional fishing days to account for wave 1, which represents only approximately one-half of one percent of the total. To derive seasonal fishing activity estimates based on the wave-level data, the number of fishing days was assumed to be the same for each month within a wave. The monthly values were then summed for the three months that compose each season (e.g. wave 2 plus one-half of wave 3's total yields the estimate for spring). Based on this approach, Exhibit 3-8 shows the breakdown of baseline recreational fishing user days by county and by season.

EXHIBIT 3-8. DELAWARE RECREATIONAL FISHING BASELINE USER DAYS BY SEASON

COUNTY NAME	WINTER	SPRING	SUMMER	FALL	SHARE OF TOTAL
New Castle County	4,229	13,335	28,730	14,357	6.41%
Kent County	13,592	42,859	92,341	46,146	20.60%
Sussex County (Bay)	21,415	67,528	145,490	72,706	32.46%
Sussex County (Atlantic)	26,738	84,315	181,657	90,781	40.53%
Total:	**65,973**	**208,037**	**448,217**	**223,990**	**Total: 946,218**
Share of Total:	6.97%	21.99%	47.37%	23.67%	

ESTIMATION OF RECREATIONAL FISHING DAYS LOST

Similar to the above analysis for beach user days, the estimated number of lost recreational fishing days for each season-specific, worst-case spill scenario is based upon the spatial intersection of shoreline oiling and recreational fishing activity. The following equation summarizes the approach for estimating spill-related reductions in recreational fishing activity:

$$RecFishing_s = \sum_{c,t} \left(F_{c,t} \times L_{c,s} \times R_{s,t}\right)$$

Where:

$RecFishing_s$ = the estimated number of lost recreational fishing days for each oil spill scenario (*s*);

$F_{c,t}$ = the baseline level of recreational fishing activity for each fishing county (*c*) and each season (*t*);

$L_{c,s}$= the percentage of recreational fishing user days in each fishing county (*c*) affected by each spill scenario (*s*), and

$R_{s,s,t}$ = for each spill scenario (*s*), the percent reduction in recreational fishing activity in each season (*t*) in the event that the shoreline is oiled as a result of the spill.

As indicated in the above equation, the reduction in recreational fishing is estimated for each fishing county for a number of seasons after a hypothetical spill occurs. These values are summed across counties and seasons to calculate the total estimated reduction in recreational fishing activity. Each of the analytic elements shown in the above equation is described further below.

Baseline Level of Recreational Fishing Activity

This value encompasses the baseline number of recreational fishing days for each fishing county and season. The development of these estimates is described in the "Baseline Recreational Fishing" section above. Because recreational fishing activity varies by season, the baseline level of recreational fishing activity potentially affected by a spill of a given size varies over the course of the year. For instance, a 900,000-barrel spill occurring in the winter will affect fewer recreational fishing days than the same modeled spill occurring in the summer.

Percentage of County-Level Recreational Fishing Days Affected by a Spill

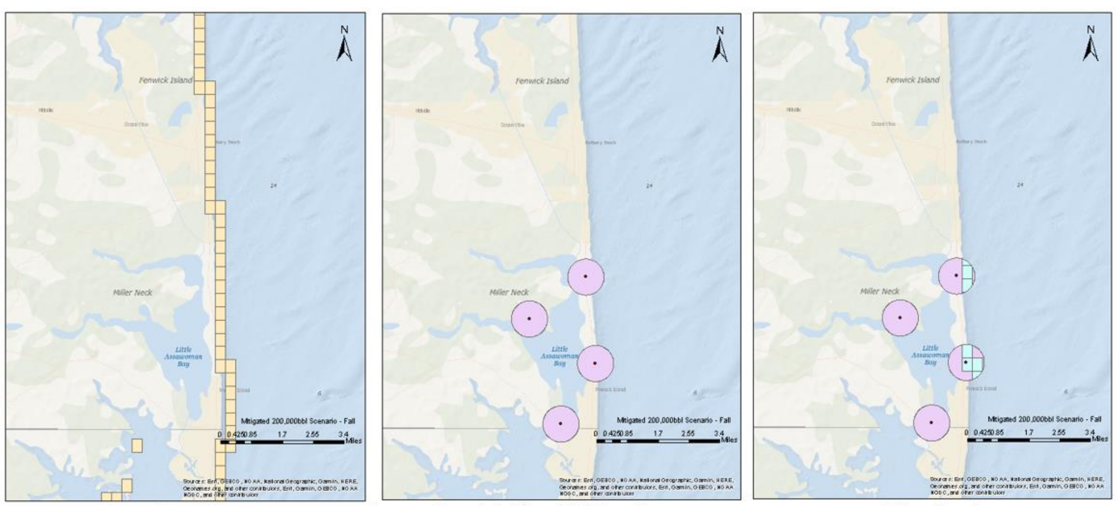
This analysis assumes that a fraction of the recreational fishing activity within each fishing county would be affected by oiling along that county's shoreline. The oiling of a portion of a county's coastline is not assumed to necessarily affect all saltwater recreational fishing in the county. To estimate the share of each fishing county's recreational fishing activity affected by oiling, this analysis integrates site-level MRIP data that characterizes fishing pressure at each fishing site with the oil spill modeling outputs described in Chapter 2. Although MRIP does not report the total level of fishing effort for individual sites, each site is given a designation indicating the range of fishing activity at the site during a six-hour period (see Exhibit 3-9). Using these data, each MRIP site was assigned a fraction of a county's recreational fishing pressure.

EXHIBIT 3-9. MRIP FISHING PRESSURE CODES

FISHING PRESSURE CODE	MRIP NUMBER OF ANGLERS OVER 6-HR PERIOD
9	0
0	1 to 4
1	5 to 8
2	9 to 12
3	13 to 19
4	20 to 29
5	30 to 49
6	50 to 79
7	80+
Source: MRIP Fishing Pressure Codes described at https://www.fisheries.noaa.gov/recreational-fishing-data/public-fishing-access-site-register	

After allocating a county's fishing pressure to individual MRIP sites, GIS projections of shoreline oiling above the critical 1 g/m^2 threshold were intersected with MRIP fishing site locations for each oil spill scenario. Exhibit 3-10 shows an example of the analysis for shoreline oiling among the fishing sites near Fenwick Island. Integrating the GIS projections with the distribution of fishing pressure across MRIP sites in a county, this analysis estimated the fraction of recreational fishing activity in a county affected by oiling. For example, if a given spill scenario led to the oiling of eight MRIP sites in a county and those eight sites accounted for 40 percent of the fishing pressure in the county, 40 percent of the recreational fishing activity in the county was assumed to be affected by the spill.

EXHIBIT 3-10. RECREATIONAL FISHING OILING OVERLAP, FENWICK ISLAND SITES



Shoreline Oiling Fenwick Island Fishing Sites Oiling Overlap

The analysis applies two variants of this approach, a "low-end" approach and a "high-end" approach, to estimate recreational fishing impacts as a range. The low end, consistent with the description above, is based on the intersection of MRIP sites with oiling above the 1 g/m^2 threshold. For the high-end, a half-mile buffer zone is added around each of the MRIP fishing sites. Thus, while the low-end specification assumes that fishing sites are affected by a spill only if there is direct overlap with modeled shoreline oiling, the high-end approach assumes that fishing sites located within half a mile of oiling may be affected. As an example, of the four fishing sites pictured in Exhibit 3-10, only one (the second-most southern) is considered affected under the low-end approach because it directly overlaps with the oiling. The high-end approach includes both the second-most southern site and the northernmost site because oiling occurs within the half-mile buffer. The analysis uses this range for recreational fishing because individual fishers may have varying tolerances for nearby oiling, for example if they stay on shore and release any fish that they catch rather than consuming them.

Percent Reduction in Recreational Fishing for Affected Areas

This analysis assumes that the proportional reduction in use for affected recreational fishing areas for a given spill scenario is equal to the proportional reduction in beach use at the Delaware beaches affected by the spill. Thus, the percent reductions presented above in Exhibit 3-5 are assumed to apply not only to beach use but to recreational fishing as well. Consistent with the beach use analysis, reductions in use are assumed to occur over multiple seasons for the 200,000-barrel surface spill scenarios and 900,000-barrel blowout scenarios. Reductions in use for the 126-barrel and 2,240-barrel scenarios are limited to the season in which the spill occurs. Also consistent with the beach use analysis, reductions in use for the surface spill are limited to oiled areas, whereas this analysis assumes separate reductions in use for the blowout scenarios: one for oiled shoreline and another for unoiled shoreline.

ESTIMATED VALUE PER LOST RECREATIONAL FISHING DAY

To estimate the welfare loss associated with lost recreational fishing days, this analysis applies the mean compensating variation for a day of marine recreational fishing in Delaware from McConnell & Strand (1994). Based on recreational anglers' expected catch, McConnell & Strand (1994) estimate a value of $20.95 per fishing day. This estimate is based on household-level survey data collected by the National Marine Fisheries Service and survey data collected by researchers at the University of Maryland. Using these data, McConnel & Strand (1994) developed statistical models to estimate the per trip value of recreational fishing for each state along the Mid-Atlantic and South Atlantic coasts.

RESULTS

Based on the methods described above, Exhibits 3-11 and 3-12 present the reduced number of recreational fishing days associated with each spill, for the calculations with and without the half-mile buffer around each fishing site. Exhibits 3-13 and 3-14 present the associated welfare losses to recreational anglers. Consistent with the beach use analysis presented above, all estimated effects are to recreational fishing activity in Delaware, though the spill locations include sites off the coasts of New Jersey and Virginia as well. As shown in the exhibits, the estimated impacts for several spill size-spill location combinations are projected as zero. Based on the oil spill modeling in described in Chapter 2, no oiling of shore-based recreational fishing sites are projected for these scenarios.

EXHIBIT 3-11. LOST RECREATIONAL FISHING USER DAYS DUE TO OILING, WORST CASE SPILL SCENARIOS, WITH HALF-MILE BUFFER

Worst Case Lost User Days due to Oiling - Recreational Fishing (With Half Mile Buffer)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	12,100	19,200	-	-
	Surface	Unmitigated 2,240bbl	30,800	57,500	26,200	-
	Surface	Unmitigated 200,000bbl	133,400	165,200	99,200	-
	Surface	Mitigated 200,000bbl	46,100	8,600	70,900	-
	Subsurface	Unmitigated 900,000bbl	372,800	304,500	213,700	231,600
New Jersey	Surface	Unmitigated 126bbl	-	20,300	-	-
	Surface	Unmitigated 2,240bbl	-	68,900	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	387,600	323,700	256,700	189,400
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	22,800	-	-
	Subsurface	Unmitigated 900,000bbl	234,200	163,900	110,600	160,300

EXHIBIT 3-12. LOST RECREATIONAL FISHING USER DAYS DUE TO OILING, WORST CASE SPILL SCENARIOS, WITHOUT HALF-MILE BUFFER

Worst Case Lost User Days due to Oiling - Recreational Fishing (Without Half Mile Buffer)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	2,000	4,500	-	-
	Surface	Unmitigated 2,240bbl	5,900	18,500	7,900	-
	Surface	Unmitigated 200,000bbl	66,500	69,900	44,400	-
	Surface	Mitigated 200,000bbl	11,200	-	15,900	-
	Subsurface	Unmitigated 900,000bbl	255,800	189,500	138,200	175,000
New Jersey	Surface	Unmitigated 126bbl	-	2,400	-	-
	Surface	Unmitigated 2,240bbl	-	20,700	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	282,700	246,400	178,200	241,700
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	-	-	-
	Surface	Unmitigated 200,000bbl	-	-	-	-
	Surface	Mitigated 200,000bbl	-	6,100	-	-
	Subsurface	Unmitigated 900,000bbl	196,200	163,900	110,600	160,300

EXHIBIT 3-13. RECREATIONAL FISHING WELFARE LOSSES, WORST CASE SPILL SCENARIOS, WITH HALF-MILE BUFFER

Worst Case Lost Use Value due to Oiling - Fishing (With Half Mile Buffer)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$ 300,000	$ 400,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ 600,000	$ 1,200,000	$ 500,000	$ -
	Surface	Unmitigated 200,000bbl	$ 2,800,000	$ 3,500,000	$ 2,100,000	$ -
	Surface	Mitigated 200,000bbl	$ 1,000,000	$ 200,000	$ 1,500,000	$ -
	Subsurface	Unmitigated 900,000bbl	$ 7,800,000	$ 6,400,000	$ 4,500,000	$ 4,900,000
New Jersey	Surface	Unmitigated 126bbl	$ -	$ 400,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 1,400,000	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ -	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 8,100,000	$ 6,800,000	$ 5,400,000	$ 4,000,000
Virginia	Surface	Unmitigated 126bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ 500,000	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 4,900,000	$ 3,400,000	$ 2,300,000	$ 3,400,000

EXHIBIT 3-14. RECREATIONAL FISHING WELFARE LOSSES , WORST CASE SPILL SCENARIOS, WITHOUT HALF-MILE BUFFER

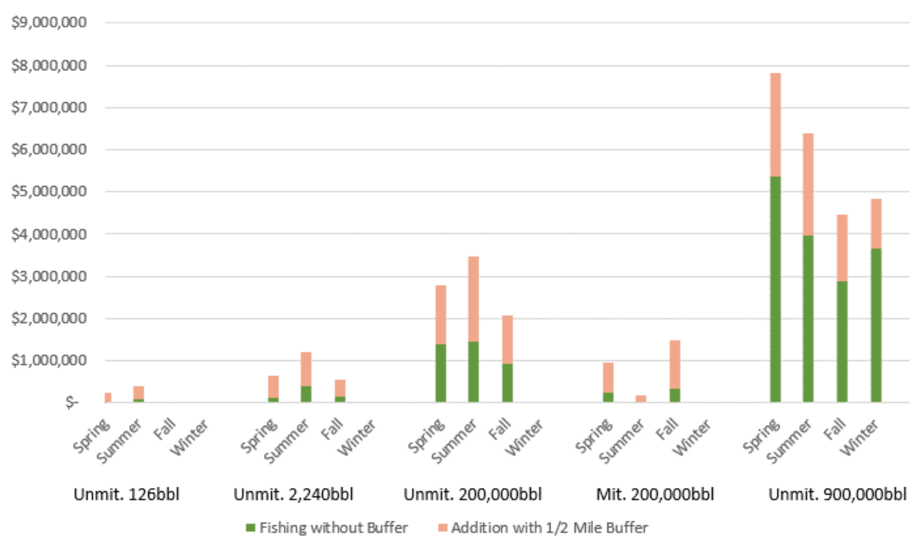
Worst Case Lost Use Value due to Oiling - Fishing (Without Half Mile Buffer)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$ -	$ 100,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ 100,000	$ 400,000	$ 200,000	$ -
	Surface	Unmitigated 200,000bbl	$ 1,400,000	$ 1,500,000	$ 900,000	$ -
	Surface	Mitigated 200,000bbl	$ 200,000	$ -	$ 300,000	$ -
	Subsurface	Unmitigated 900,000bbl	$ 5,400,000	$ 4,000,000	$ 2,900,000	$ 3,700,000
New Jersey	Surface	Unmitigated 126bbl	$ -	$ 100,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 400,000	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ -	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 5,900,000	$ 5,200,000	$ 3,700,000	$ 5,100,000
Virginia	Surface	Unmitigated 126bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ 100,000	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 4,100,000	$ 3,400,000	$ 2,300,000	$ 3,400,000

The seasonal pattern of impacts for recreational fishing is similar to that summarized above for beach use, with impacts generally more significant during the summer than other seasons. A key exception to this finding is the 900,000-barrel blowout scenarios, which are projected to result in more significant fishing impacts when they occur during the spring due to the multi-seasonal impact of these scenarios. Another exception to the expected seasonality of impacts is the 200,000-barrel mitigated spills off the coast of Delaware. The fall variant of this spill is projected to result in more significant recreational fishing impacts than the summer variant. This reflects how the pattern of mitigation applied in the oil spill modeling affects the spatial distribution of shoreline oiling relative to the MRIP fishing sites described above. During summer conditions, mitigation of a 200,000-barrel spill is projected to more effectively prevent the oiling of relatively high-use fishing sites on Delaware's coast.

Similar to beach use, spill-related impacts for recreational fishing are highest for the Delaware spill locations, due to their close proximity to the Delaware shoreline. Fishing impacts are also generally higher for the larger spill scenarios, with the exception noted in the beach use results discussion concerning the 200,000-barrel scenarios for the New Jersey spill locations. As noted above, the worst-case conditions for these scenarios suggest significant shoreline oiling along the New Jersey and Long Island coasts but no oiling on the Delaware coast. The appendix to this report includes estimates of recreational impacts for the 200,000-barrel spills at the New Jersey locations assuming the same wind and current conditions as applied for the 2,240-barrel spills off New Jersey's coast.

Exhibit 3-15 presents an additional perspective on the upper- and lower-bound welfare results for each of the spill scenarios off the Delaware coast. The difference between the endpoints of the range is more pronounced for the surface spills than for the subsurface blowout scenarios, though in each case the upper bound effect size is more than 25 percent larger than the lower bound. In some cases, such as the summer 200,000-barrel mitigated scenario, the addition of the buffer captures an effect where the no-buffer method does not. Methodologically, this difference is due to the elimination of "near miss" events in the oiling spatial overlap exercise, where oiling might be very close to but not quite reach specific fishing site locations. This result also shows that losses to recreational anglers are dependent on the degree to which they are reluctant to engage in fishing activity in areas that are not oiled but are nevertheless in close proximity to oiled areas.

EXHIBIT 3-15. RECREATIONAL FISHING VALUE LOSS ESTIMATES, DELAWARE



RECREATIONAL BOATING

Complementing the assessment of beach and fishing losses presented above, this analysis also examines spill-related welfare losses for recreational boating. This section presents the assessment of these losses for each of the oil spill scenarios describe in Chapter 2. The structure of this analysis is similar to that for beach use and recreational fishing as presented above, and includes estimation of baseline recreational boating activity (for boats based in Delaware), the specification and application of assumptions regarding reductions in boating activity, and calculation of the welfare losses associated with reduced boating activity.

BASELINE BOATING ACTIVITY

To estimate baseline activity, this analysis relies on boat registration data from DNREC and boat use data from the Monmouth University Urban Coast Institute's Mid-Atlantic Recreational Boater Survey and the Mid-Atlantic Regional Council on the Ocean (MARCO) Mid-Atlantic Ocean Data Portal.[22] The 2016 survey provides estimated boat trips per Delaware boat owner for the months of May to October. Applying these values to the 60,000 boats registered in Delaware according to DNREC yields estimates of recreational boat days per month between May and October.[23] To account for the number of people participating in the typical boating day, this analysis assumes 2.64 individuals per boat trip, based on data collected for the assessment of boating impacts for the *Deepwater Horizon* Natural Resource Damage Assessment (Lupi 2015). While this analysis would ideally apply an estimate of individuals per trip specific to Delaware or the Mid-Atlantic, no such value was readily available.

As noted above, the MARCO data capture boating activity from May to October. To account for boating during the off-season months of November to April, this analysis relies on 2019 Automatic Identification System (AIS) data for recreational boaters from the MARCO data portal, which provides location tracking for a small sample of recreational boaters throughout all 12 months. These data provide information on the level of boating activity for one month relative to others. Based on these relative relationships, the boating activity estimates for the May to October period were scaled to derive estimates for November to April.

An additional, though much smaller, recreational boating category concerns individuals taking charter fishing trips and private party boat cruises. Data on this boating activity were obtained from the NOAA MRIP dataset used in the recreational fishing baseline activity calculations. As noted above, these boating trips were excluded from the recreational fishing estimates to avoid double counting. Altogether, charter and private party boat cruises add approximately 4,700 recreational boater days, or one-tenth of one percent of the total (see below for total).

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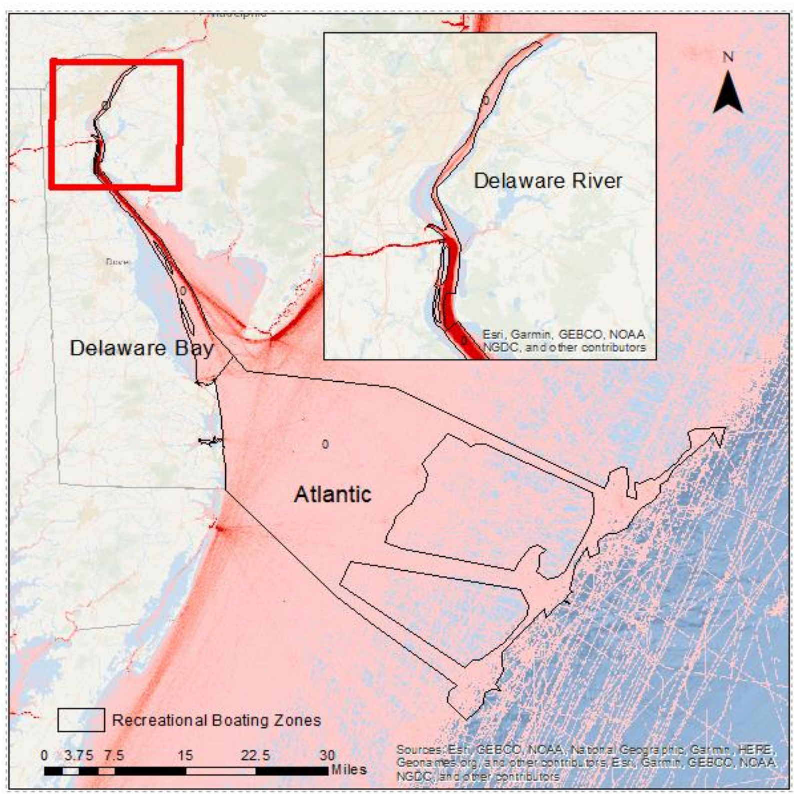
[22] See Urban Coast Institute, Monmouth University (2016) and the MARCO Mid-Atlantic Ocean Data Portal at https://portal.midatlanticocean.org/.

[23] See Delaware Executive Department Office of Management and Budget (2017).

For the purposes of this analysis, boat trips by Delaware boaters were spatially distributed between the Atlantic (including inland bays on the Atlantic), Delaware Bay, and the lower waters of the Delaware River (see Exhibit 3-16). Boating activity was split between these specific zones so that the analysis may account for how different boater groups might respond to a spill. For example, for a spill that stays on the Atlantic and does not enter Delaware Bay, boaters on Delaware Bay or on the lower Delaware River may be less likely to cancel boat trips than boaters on the Atlantic. To allocate boat trips to these three zones, this analysis relies on AIS data for boats classified as "pleasure crafts" in the MARCO portal. Boating activity is calculated within each of the zones by measure of the number of AIS locating points that boats send out while in use, or "vessel pings." If a boat spends more time in one area, the result is more total pings captured by AIS. Thus, a limitation of the AIS data is that they reflect not only the number of trips but the duration of trips in the different boating zones. To the extent that the duration of boating trips systematically differs between zones, the spatial allocation of boating trips based on the AIS data may therefore be skewed. No information was available, however, to suggest such systematic differences. Exhibit 3-17 shows estimated baseline boating activity user days for each boating zone and across each season.

EXHIBIT 3-16. DELAWARE RECREATIONAL FREQUENT BOATING ZONES OVERLAID ON 2019 AIS DATA FOR RECREATIONAL BOATING TRIPS



Note: The Atlantic frequent boating zone has three legs out toward the continental shelf as these are the paths typically taken by pleasure crafts, as

EXHIBIT 3-17. DELAWARE RECREATIONAL BOATING BASELINE USER DAYS BY SEASON

BOATING ZONE	WINTER	SPRING	SUMMER	FALL	SHARE OF TOTAL
Delaware River	4,159	77,281	218,060	143,921	9.16%
Delaware Bay	17435.642	324,012	914,249	603,409	38.40%
Atlantic	23,807	442,432	1,248,388	823,942	52.44%
Total	**45,402**	**843,725**	**2,380,697**	**1,571,272**	**Total: 4,841,097**
Share of Total	0.94%	17.43%	49.18%	32.46%	

ESTIMATION OF RECREATIONAL BOATING DAYS LOST

To estimate the reduction in recreational boating activity associated with individual spill scenarios, this analysis combines the baseline data presented above with information on projected surface oiling according to the following equation:

$$RecBoating_s = \sum_{z,t} (V_{z,t} \times L_{z,s} \times R_{s,t,z})$$

Where:

$RecBoating_s$ = the estimated reduction in boating user days for each oiling scenario (s).

$V_{z,t}$ = the baseline level of recreational boating activity for each boating zone (z) in each season (t).

$L_{z,s}$ =a binary indicator of whether oiling occurs in each boating zone (z) under each spill scenario (s), set equal to 1 if a boating zone is oiled and 0 if it is not oiled, and

$R_{s,t,z}$ = percentage use reduction under oiling scenario (s) in each season (t) when a given boating zone (z) is oiled.

As shown in the above equation, this analysis estimates the reduction in boating activity by boating zone and by season after a spill occurs. These impacts are summed across boating zones and seasons to derive estimates of total boating impacts for a scenario. The following sections describe each analytic element of the above equation.

Baseline Level of Boating Activity ($V_{a,t}$)

This value encompasses the baseline recreational boater days for each boating zone in each season. The development of these estimates is described in the "Baseline Recreational Boating" section above. Note that spills of the same size with similar floating oil on the water surface may have varying effects on recreational boating levels depending on the season during which the spill occurs. For instance, the effects of a 900,000-barrel spill occurring during the winter will be limited to low-traffic months, while the same modeled spill occurring in the summer will lead to much more significant boating impacts.

Indicator of Oiling by Boating Zone ($L_{z,s}$)

Based on projections of surface oiling for each spill scenario, this indicator is set equal to 1 if a boating zone has surface oiling above the critical threshold of 0.1 g/m^2 and is set equal to 0 if there is no surface oiling in a given boating zone. Even if just a small portion of a boating zone is oiled above the threshold, this value is set equal to 1.

Reduction in Use Within a Boating Zone if Oiling Occurs ($R_{s,t,z}$)

The assumed reduction in use when a boating zone is oiled varies across the different spill size scenarios included in this analysis. In descending order of spill size, these assumptions are as follows:

- ***900,000-barrel blowout scenarios:*** Following the 2010 *Deepwater Horizon* blowout, the Natural Resource Trustees estimated that recreational boating activity in the Gulf of Mexico declined by 28 percent over a period of three months (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). Based on this experience and absent other information on the boating impacts of major well blowout events, this analysis assumes a 28 percent reduction over three months (a single season) for any boating zone that is oiled under a given spill scenario.

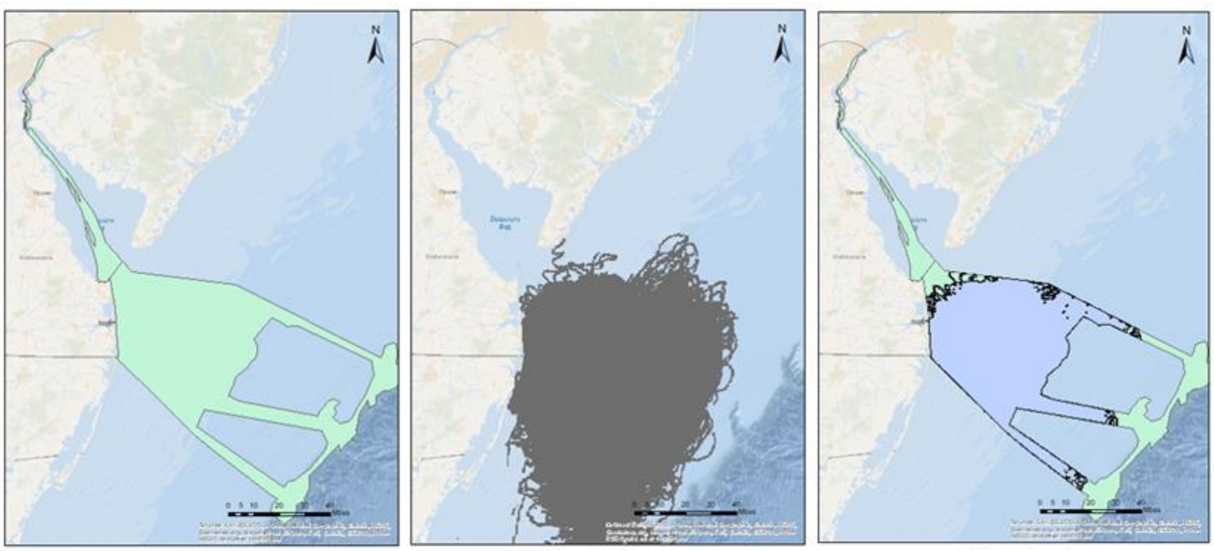
- ***200,000-barrel surface spill scenarios:*** Absent boating studies on spills of this magnitude, the assumptions for these spill scenarios are also based on the estimated reduction in boating associated with the *Deepwater Horizon* spill. In contrast to the 900,000-barrel blowout scenarios, which involve the release of oil from a well over a period of 30 days, the release of oil for the 200,000-barrel surface spills is assumed to occur over a period of just one hour, as described in Chapter 2. To maintain consistency with the 900,000-barrel spill assumptions regarding the duration of impacts *after the release of oil has ended*, this analysis assumes that the duration of reduced boating activity for the 200,000-barrel spill is two months. This analysis further assumes a 28 percent reduction in use over this two-month period for any boating zone with oiling above the 0.1 g/m^2 threshold.

- ***2,240-barrel surface spill scenarios:*** For the 2,240-barrel spill scenarios, the duration of reduced boating activity in an oiled recreational boating zone is assumed to be 10 days, or approximately half the duration of effects for beach use and recreational fishing. Because the magnitude of the reduction during this period is somewhat uncertain, this analysis specifies a range for the reduction in effects. At the high end of the range, this analysis assumes that all boating activity in the oiled boating zone ceases for the full 10-day period. In effect, this amounts to a 10-day closure in the oiled boating zone following the spill. Absent a formal closure, the curtailment of all boating activity during this period would also be consistent with boaters avoiding the risk of oiling their boats and incurring costs for oil removal.

At the low end of the range, this analysis assumes that some boating activity will continue and that at least some boaters will maneuver their boats around floating oil to avoid the oiling of their boats. Thus, rather than assuming that all boating activity is curtailed for 10 days, the low end assumption is that the reduction in boating activity in an oiled boating zone is proportionate to the share of the boating zone that is oiled above the 0.1 g/m^2 threshold. As an example, in the Atlantic boating zone pictured in Exhibit 3-18, 81 percent of the boating zone is affected by oiling, so the lower-bound scenario assumes an 81 percent reduction in recreational boating activity during the 10-day impact period.

- ***126-barrel surface spill scenarios:*** The assumptions for the 126-barrel spill scenarios are similar to those described above for the 2,240-barrel scenarios. The main difference is that the assumed duration of impacts is 5 days, which is approximately half the duration of effects for beach use and recreational fishing. Similar to the 2,240-barrel scenarios, impacts are estimated as a range, with the high end assuming that all recreational boating activity is curtailed in an oiled recreational boating zone for the 5-day impact period and the low end assuming that the reduction in boating is proportional to the surface area oiled in the boating zone.

EXHIBIT 3-18. BOATING OILING OVERLAP, ATLANTIC BOATING ZONE



Recreational Boating Zones | Surface Oiling | Oiling Overlap

ESTIMATED VALUE PER LOST RECREATIONAL BOATING DAY

To assign a dollar value to the lost recreational boating days due to surface oiling, this analysis applies the consumer surplus per boating day from Johnston et al. (2002). The paper presents mean values per boating user day for the Peconic Estuary off of Long Island, NY. The value, inflated to 2019 dollars, is $30.04 per recreational boating day. Multiplying this value by the number of lost user days in each boating zone due to oiling and summing the results across zones yields the estimated welfare losses for boating for a given oil spill scenario.

RESULTS

Following the approach outlined above, Exhibits 3-19 and 3-20 show the estimated reduction in boating activity for each oil spill scenario. Exhibits 3-21 and 3-22 outline the corresponding welfare losses associated with these reductions in boating activity. All estimated effects are to recreational boating activity off the coast of Delaware, though oil spill locations off the coasts of New Jersey and Virginia are included in the analysis.

Consistent with the beach use and recreational fishing results described above, impacts for recreational boating are generally most significant during the summer and for higher-volume spills. The relatively high effects for summer spills reflect the peak boat-use summer season, which accounts for nearly half of all annual boating days (see Exhibit 3-17 above). The higher effects projected for the high-volume scenarios reflect more extensive surface oiling for these spill scenarios relative to others, in terms of whether surface oil reaches the boating zones shown in Exhibit 3-16 and the extent of oiling in a given boating zone in the event that it is oiled.

The results show two exceptions to these patterns. First, the 200,000-barrel summer spills off the coast of New Jersey show lower boating impacts than the 2,240- and 126-barrel spills. As described in the beach use and recreational fishing sections above, this result reflects the fact that the worst-case conditions for the 200,000-barrel summer spill sent spilled oil northward, significantly affecting areas off the coasts of New Jersey and New York while waters off the coast of Delaware were unaffected. The appendix to this report includes an alternative specification of the 200,000-barrel summer scenarios off New Jersey that reflect the same wind and currents as assumed for the 2,240- and 126-barrel scenarios.

The second exception is the 900,000-barrel blowout scenario off the coast of Virginia in the summer. Under the lower bound assumptions, boating impacts for this spill are less than those for the 200,000-barrel scenarios. This reflects the assumed location of the 900,000-barrel spills. As described in Chapter 2, these spills are assumed to be much farther from the coast than the surface spills and may, depending on the conditions, lead to less oiling of recreational areas than smaller spills in closer proximity to the coast.

EXHIBIT 3-19. LOST RECREATIONAL BOATING USER DAYS DUE TO OILING, LOWER BOUND

Worst Case Lost User Days due to Oiling - Boating (Low End - Proportional)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	600	2,500	700	-
	Surface	Unmitigated 2,240bbl	38,500	152,200	42,500	100
	Surface	Unmitigated 200,000bbl	102,800	347,100	113,200	200
	Surface	Mitigated 200,000bbl	61,200	236,100	77,900	200
	Subsurface	Unmitigated 900,000bbl	210,800	582,200	292,600	6,400
New Jersey	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	50,200	100	1,100
	Surface	Unmitigated 200,000bbl	-	-	79,300	3,600
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	214,300	467,300	384,400	10,800
Virginia	Surface	Unmitigated 126bbl	-	-	-	-
	Surface	Unmitigated 2,240bbl	-	500	-	-
	Surface	Unmitigated 200,000bbl	-	30,600	-	-
	Surface	Mitigated 200,000bbl	-	204,700	-	-
	Subsurface	Unmitigated 900,000bbl	126,000	4,000	4,600	700

EXHIBIT 3-20. LOST RECREATIONAL BOATING USER DAYS DUE TO OILING, UPPER BOUND

Worst Case Lost User Days due to Oiling - Boating (High End - Binary)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	42,000	118,500	45,200	1,300
	Surface	Unmitigated 2,240bbl	88,200	274,000	164,300	2,700
	Surface	Unmitigated 200,000bbl	143,100	444,400	266,400	4,400
	Surface	Mitigated 200,000bbl	82,600	403,700	266,400	4,400
	Subsurface	Unmitigated 900,000bbl	236,200	666,600	399,700	11,500
New Jersey	Surface	Unmitigated 126bbl	-	118,500	-	1,300
	Surface	Unmitigated 2,240bbl	-	248,900	94,800	4,700
	Surface	Unmitigated 200,000bbl	-	-	153,800	7,700
	Surface	Mitigated 200,000bbl	-	-	-	-
	Subsurface	Unmitigated 900,000bbl	236,200	605,500	399,700	11,500
Virginia	Surface	Unmitigated 126bbl	-	68,400	-	-
	Surface	Unmitigated 2,240bbl	-	143,700	-	-
	Surface	Unmitigated 200,000bbl	-	233,000	-	-
	Surface	Mitigated 200,000bbl	-	233,000	-	-
	Subsurface	Unmitigated 900,000bbl	214,600	349,500	230,700	6,700

EXHIBIT 3-21. LOST RECREATIONAL BOATING USE VALUE DUE TO OILING, LOWER BOUND

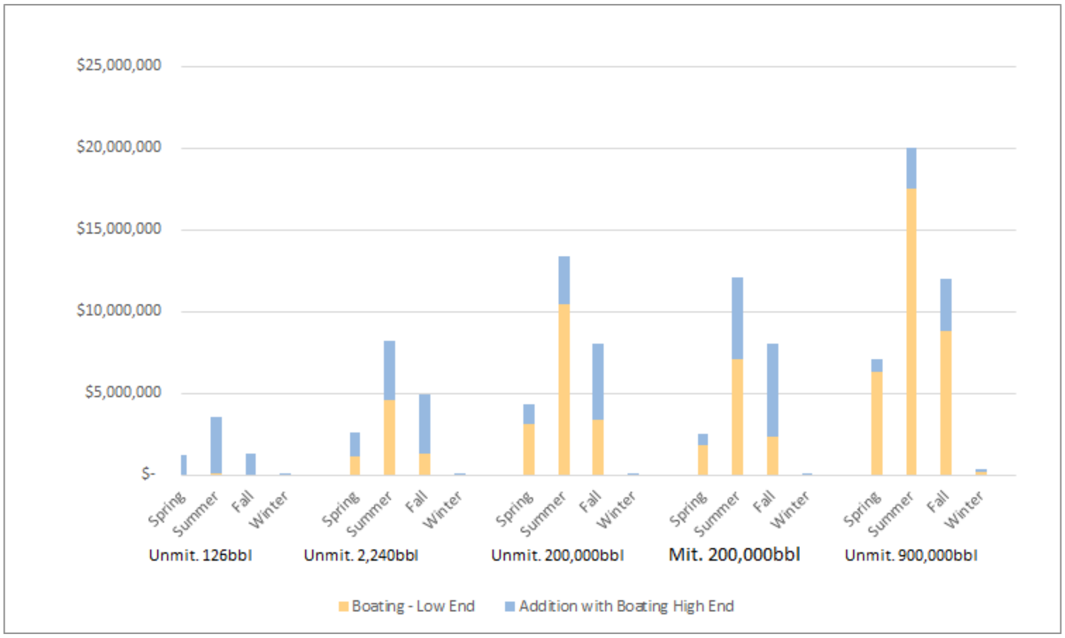
Lost Use Value due to Oiling - Boating (Low End - Proportional)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$ -	$ 100,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ 1,200,000	$ 4,600,000	$ 1,300,000	$ -
	Surface	Unmitigated 200,000bbl	$ 3,100,000	$ 10,400,000	$ 3,400,000	$ -
	Surface	Mitigated 200,000bbl	$ 1,800,000	$ 7,100,000	$ 2,300,000	$ -
	Subsurface	Unmitigated 900,000bbl	$ 6,300,000	$ 17,500,000	$ 8,800,000	$ 200,000
New Jersey	Surface	Unmitigated 126bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 1,500,000	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ 2,400,000	$ 100,000
	Surface	Mitigated 200,000bbl	$ -	$ -	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 6,400,000	$ 14,000,000	$ 11,500,000	$ 300,000
Virginia	Surface	Unmitigated 126bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ -	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ 900,000	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ 6,100,000	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 3,800,000	$ 100,000	$ 100,000	$ -

EXHIBIT 3-22. LOST RECREATIONAL BOATING USE VALUE DUE TO OILING, UPPER BOUND

Lost Use Value due to Oiling - Boating (High End - Binary)						
Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$ 1,300,000	$ 3,600,000	$ 1,400,000	$ -
	Surface	Unmitigated 2,240bbl	$ 2,600,000	$ 8,200,000	$ 4,900,000	$ 100,000
	Surface	Unmitigated 200,000bbl	$ 4,300,000	$ 13,300,000	$ 8,000,000	$ 100,000
	Surface	Mitigated 200,000bbl	$ 2,500,000	$ 12,100,000	$ 8,000,000	$ 100,000
	Subsurface	Unmitigated 900,000bbl	$ 7,100,000	$ 20,000,000	$ 12,000,000	$ 300,000
New Jersey	Surface	Unmitigated 126bbl	$ -	$ 3,600,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 7,500,000	$ 2,800,000	$ 100,000
	Surface	Unmitigated 200,000bbl	$ -	$ -	$ 4,600,000	$ 200,000
	Surface	Mitigated 200,000bbl	$ -	$ -	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 7,100,000	$ 18,200,000	$ 12,000,000	$ 300,000
Virginia	Surface	Unmitigated 126bbl	$ -	$ 2,100,000	$ -	$ -
	Surface	Unmitigated 2,240bbl	$ -	$ 4,300,000	$ -	$ -
	Surface	Unmitigated 200,000bbl	$ -	$ 7,000,000	$ -	$ -
	Surface	Mitigated 200,000bbl	$ -	$ 7,000,000	$ -	$ -
	Subsurface	Unmitigated 900,000bbl	$ 6,400,000	$ 10,500,000	$ 6,900,000	$ 200,000

Exhibit 3-23 presents the upper- and lower-bound results for the Delaware spill scenarios in bar chart form. The difference between the endpoints of the range is less pronounced than the range for recreational fishing. The graph nevertheless highlights the sensitivity of estimated boating impacts to assumptions regarding the reluctance of boaters to take their boats into potentially oiled waters.

EXHIBIT 3-23. RECREATIONAL BOATING VALUE LOSS ESTIMATES, DELAWARE



KEY UNCERTAINTIES

The analysis presented in this chapter draws on the best available data to provide insights into the potential recreational impacts to Delaware associated with spills occurring in the Mid-Atlantic. It is important to acknowledge, however, that the analysis is subject to a number of uncertainties, the most significant of which are as follows:

- The analysis relies on assumptions about the reduction in recreational activity based on limited information available on observed reductions for past spills. While these assumptions provide a reasonable basis for estimating potential impacts, the reduction in recreational activity for a given spill would depend on a number of spill- and location-specific factors not captured in this analysis. Such factors may include, for example, the presence or absence of amenities such as boardwalks that do not involve contact with the water and attitudes of the local population regarding potential exposure to oil. Due to these site- and spill-specific considerations, the reduction in use associated with a given spill could differ from the assumptions applied in this analysis.

- As designed, this analysis estimates impacts based on the reduction in use in the area affected by a spill. If a spill were to occur, however, some individuals may instead engage in marine recreation at other sites, mitigating the impact of the spill. To the extent that recreators engage in this mitigating behavior, this analysis may overestimate recreational impacts.

- For the surface spill scenarios, the beach and fishing analyses focus on impacts projected to be oiled under a given scenario. If a spill were to occur, however, beach use and fishing activity could also decline in other areas if beachgoers and fishers are concerned about spilled oil migrating to these areas, in which case this analysis would underestimate potential impacts.
- The welfare estimates presented in this analysis are based on findings from the literature on the value of a user day. While the studies chosen are broadly applicable to marine recreation off Delaware's coast, user day values for specific locations in Delaware may differ from the values used in this analysis, due to site-specific factors related to resource quality, such as beach size, crowd density, water clarity, scenic vistas, etc.

CHAPTER 4 | COMMERCIAL FISHING

This chapter presents the analysis of impacts to Delaware's commercial fishing industry from each of the oil spill scenarios described in Chapter 2. Impacts to the commercial fishing industry are defined as lost landings revenue relative to baseline levels of commercial fishing in the state. This chapter focuses solely on the impacts to Delaware's commercial fishery and does not account for potential damages to other, nearby fisheries (e.g., New Jersey, New York, or Virginia). Impacts to Delaware's commercial fishing industry may also affect employment, gross domestic product (GDP), and household income in the state. However, these impacts are not quantified as part of the commercial fishing analysis; they are reflected in the economic impact analysis presented in Chapter 7. The following sections describe the data sources and methodology used to estimate the extent of oiling damages to the Delaware commercial fishing industry and presents results for the spill severities, locations, and seasons described in Chapter 2.

DATA SOURCES

In addition to the oil spill modeling scenarios, the analysis of impacts to the Delaware commercial fishery relies on several data sources to estimate baseline revenues, spatially distribute fishing activity in Delaware coastal and marine waters, and assess total impacts due to closures stemming from the potential oil spill scenarios.

BASELINE COMMERCIAL FISHING REVENUE

To estimate baseline landings revenue, this analysis relies on data provided by the Delaware Department of Natural Resources and Environmental Control (DNREC). The data provided are the official commercial landings (dollars and pounds) for 2018 by species. Exhibit 4-1 presents the top ten species by landings revenue in the 2018 DNREC data, as well as total landings for the state.

The commercial landings data provided by DNREC are generally equivalent to the publicly available data maintained by the NOAA National Marine Fisheries Service (NMFS). However, there are often minor discrepancies between the states and NMFS landings due to landings reported to the states after the NMFS submission deadline, species listed as confidential, and NMFS' use of the "Unidentified Species" category. As evidenced by Exhibit 4-1 below, the total value of Delaware's commercial fishery is roughly $11.67 million per year as of 2018. This means that if an oil spill resulted in the closure of the entirety of the fishery for a year, lost revenues would not exceed $11.67 million.

EXHIBIT 4-1. DNREC 2018 COMMERICIAL LANDINGS, TOP TEN SPECIES ($2019)

SPECIES	VALUE ($2019)	POUNDS
Blue Crab	$8,565,130	4,263,213
Knobbed Conch	$719,680	294,605
Oyster	$616,538	106,904
Black Sea Bass	$613,655	169,078
Striped Bass	$567,098	155,028
Horseshoe Crab Male	$224,554	378,195
American Eel	$98,505	31,378
Smooth Conch	$76,941	14,398
Hard Clam	$74,310	20,236
American Lobster	$41,282	14,592
All others	$76,231	280,094
Total (all species):	**$11,673,922**	**5,727,721**

TEMPORAL DISTRIBUTION OF BASELINE REVENUES

To assess impacts of a potential oil spill scenario, the analysis distributes DNREC baseline landings to each month. Doing this allows the analysis to estimate the impacts of oil spill scenarios that require closures of less than 12 months in duration.

To develop this distribution, the analysis relies on DNREC's summary of current commercial fish regulations for 2020.[24] Using the commercial season specified by DNREC, the analysis estimates the portion of total landings attributable to each month. For each species, landings are assumed to be evenly distributed throughout the open season. For example, if the open season for a given species is year-round, then each month will account for roughly 8 percent of annual revenue (100 percent ÷ 12 = 8.33 percent). For species in the DNREC landings data without a match in the commercial fish regulations, the analysis assumes that the fishing season is open year-round and distributes landings evenly across the 12 months. Exhibit 4-2 presents the monthly commercial season distribution for the top ten species by landings revenue. The percentages for each month are applied to the annual landings estimates from DNREC to estimate monthly landings by species.

24 DNREC. 2020. Summary of Current Commercial Fish Regulation in Delaware for 2020. http://www.dnrec.delaware.gov/fw/Fisheries/Documents/SummaryCommRegs.pdf

EXHIBIT 4-2. MONTHLY DISTRIBUTION, TOP TEN SPECIES

SPECIES	COMMERCIAL SEASON	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
American eel	Year-round	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
American Lobster	Year-round (pending seasonal closures)	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Black sea bass	Year-round	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Blue Crab	Mar 1 – Nov 30	0%	0%	11%	11%	11%	11%	11%	11%	11%	11%	11%	0%
Hard Clam	Closed Sundays from Memorial to Labor Day[25]	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Horseshoe Crab Male	Closed Jan. 1- June 7 (No harvest Sat. and Sun. after June 7).	0%	0%	0%	0%	0%	11%	15%	15%	15%	15%	15%	15%
Knobbed Conch	Year-round	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Oyster	Apr 1 – May 30; September 1 – December 31	0%	0%	0%	17%	17%	0%	0%	0%	17%	17%	17%	17%
Smooth Conch	Year-round	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Striped bass	Feb 15 – May 51	0%	14%	29%	29%	29%	0%	0%	0%	0%	0%	0%	0%

Note: Values across a given row may not sum to 100 percent due to rounding.

25 Assumed to be open year-round.

Exhibit 4-3 presents the distribution of annual commercial revenue by month. As evidenced by the chart, landings revenues are greatest during the late spring through the fall and drop dramatically during the winter months.

EXHIBIT 4-3. 2018 MONTHLY COMMERCIAL LANDINGS REVENUE (ALL SPECIES - $2019)

SPATIAL DISTRIBUTION OF BASELINE REVENUES

In addition to distributing baseline commercial fishing landings by month, this analysis also allocates landings revenue spatially, using a raster dataset developed by the NOAA Northeast Fisheries Science Center (NFSC).[26] The NSFC fishing-intensity raster dataset allows users to visualize the spatial representation of self-reported Vessel Trip Report (VTR) fishing locations and the landings revenue (in year 2012 dollars) associated with commercial fishing trips. The Delaware-specific raster dataset covers all species and gear categories for 2007 through 2012. This analysis utilizes the raster dataset to estimate the proportion of overall commercial fishing activity in each cell of a set of 6.5 mile by 6.5 mile grid cells covering the spatial extent of commercial fishing activity in Delaware coastal waters as represented by the raster data. Exhibit 4-4 presents the Delaware raster dataset from NFSC and the translation to grided data. The darker orange and red colors indicate areas with high fishing activity as measured by landings revenue.

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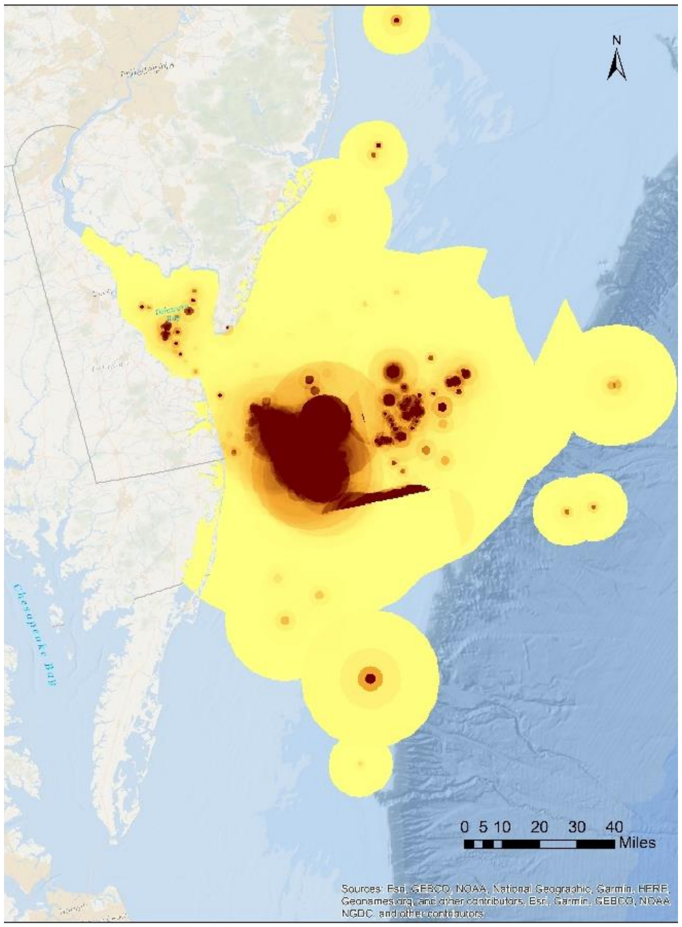
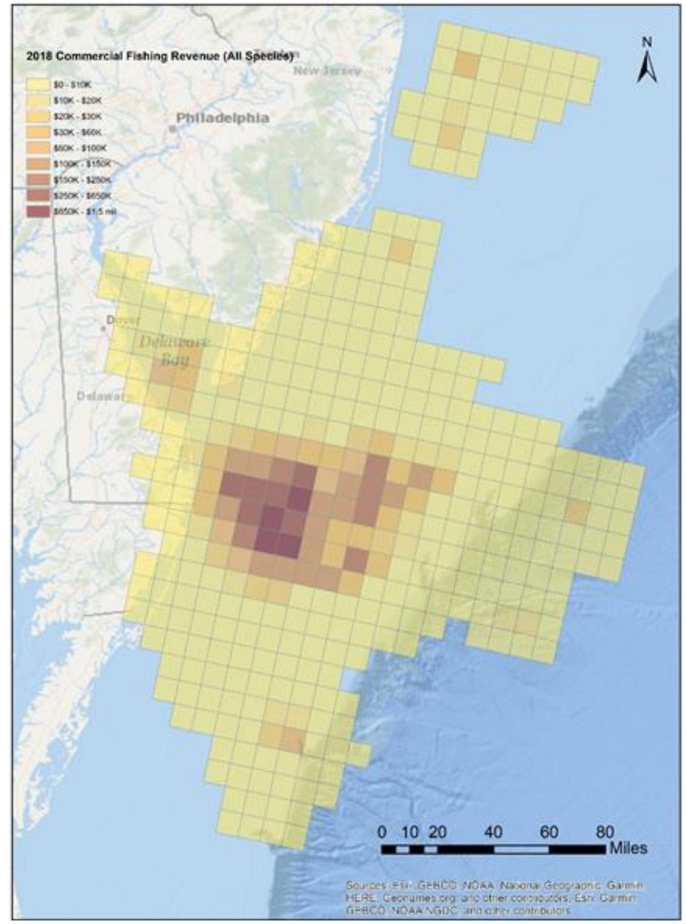
[26] Benjamin S, Lee MY, DePiper G. 2018. Visualizing fishing data as rasters. NEFSC Ref Doc 18-12; 24 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at https://www.nefsc.noaa.gov/publications/

EXHIBIT 4-4. NSFC RASTER DATA SET AND TRANSLATION TO GRIDDED DATA





METHODOLOGY

The methodology underlying the commercial fishing analysis involves the following steps:

- Estimate baseline, species-level commercial fishing landings using the 2018 dataset provided by DNREC (described above).
- Apportion species-level baseline landings revenue to each month based on the open commercial fishing season for each species present in the DNREC data (described above).
- Distribute baseline monthly landings revenue spatially using the NFSC fishing intensity raster dataset (described above).
  - Overlay 6.5 by 6.5-mile grid cells onto the NSFC raster dataset and calculate the proportion of overall fishing activity (%) accounted for by each grid cell.
  - Apply the proportions to baseline, monthly landings revenue for all species to estimate the level of baseline monthly fishing activity in each grid cell.
- For each spill scenario, determine whether a grid cell experiences any oiling.
  - For oiled grid cells, assume commercial fishing activity is suspended for the closure duration associated with the spill scenario size.
  - The closure duration is assumed to begin on the first month of the spill scenario season. For example, the lower bound closure (3 months) for the unmitigated, spring 200,000-barrel scenario would extend from April 1st through the end of June.
- Sum the monthly landings revenue for each month and oiled grid cell combination during which the fishery is assumed to be closed.

The following sections include additional detail describing the lost revenue calculations.

LOST REVENUE CALCULATION

The following equation summarizes the derivation of the lost revenue calculation utilizing the data sources and methodology described above:

$$\boldsymbol{LR_g = (OA \cap GC) \times \sum_t \left(R_{g,t} \times C_t\right)}$$

Where:

LR_g = the estimated lost commercial fishing revenue for the grid cell (g).

OA = the spatial extent of surface oiling,

GC = the geographic location of the commercial fishing grid cell.

(OA ∩ GC) = the union of surface oiling and the commercial fishing grid cell. This is calculated via ArcGIS and assumes the value of 0 if there is no surface oiling in the grid cell and 1 if there is any surface oiling present in the grid cell.

R_t = Total commercial landings revenue for all species for the grid cell (*g*) during months (*t*) over which there is an oiling impact/closure.

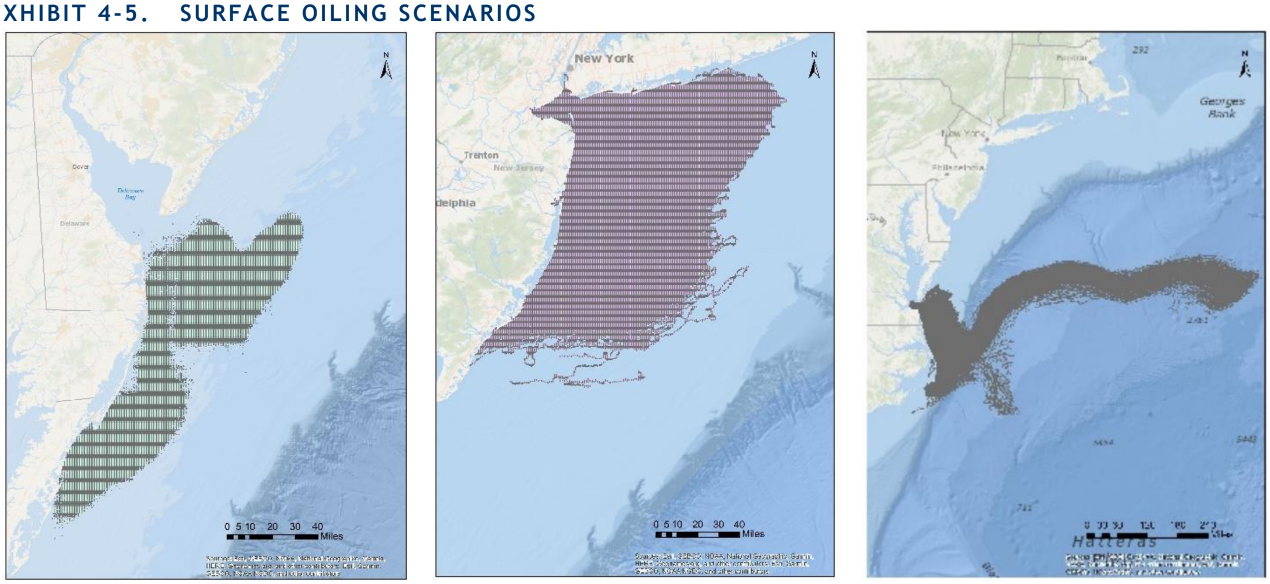
C_t = The closure indicator during months (*t*). Assumes the value of 0 if the area is not closed to commercial fishing in given month (*t*) and 1 if the area is closed to commercial fishing activity.

After estimating LR_g for each grid cell, lost commercial fishing revenues are summed across all species and months for each of the 6.5 by 6.5 mile grid cells. This same calculation is repeated for each spill scenario to estimate effects for the suite of modeled surface oiling spill scenarios. The main analytic elements included in the above equation are descibed further below.

Surface Oiling (OA)

The extent and concentration of surface oiling is determined by assessing the oil spill scenarios detailed in Chapter 2 using ArcGIS. Exhibit 4-5 includes a set of maps detailing the spatial extent of the following oil spill scenarios: (1) Delaware unmitigated 126-barrel surface spill in the spring, (2) New Jersey unmitigated 200,000- barrel spill in the spring, and (3) Virginia unmitigated 2,240-barrel surface spill in the spring.

EXHIBIT 4-5. SURFACE OILING SCENARIOS



DE unmitigated 126-bbl, spring *NJ unmitigated 200,000-bbl, spring* *VA unmitigated 2,240-bbl, spring*

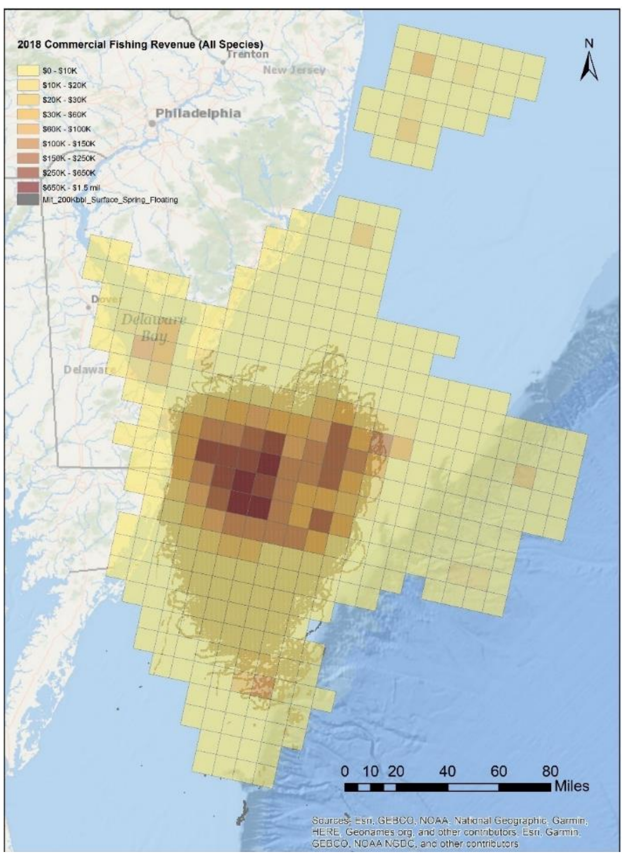
Baseline Level of Commercial Fishing Activity (grid cells – GC)

To estimate baseline commercial fishing activity, this analysis utilizes the DNREC 2018 commercial landings data, the temporal distribution implied by DNREC commercial fishing regulations, and the NSFC raster dataset, as summarized in the data sources section above.

Overlay/Union Analysis (OA ∩ GC)

To identify the baseline fishing activity affected by surface oiling, this analysis relies upon a GIS spatial union of modeled oiling for each spill scenario and the fishing grid cells derived from the NFSC raster dataset. For each spill scenario, the GIS analysis projected surface oiling in coastal waters for the set of 6.5 by 6.5 mile grid cells. A given commercial fishing grid cell was considered oiled above a threshold of concern if the total oil concertation in that grid cell exceeded the threshold value of 0.1 g/m^2 identified in Chapter 2. The gridded projection of surface oiling above this threshold was overlaid on the gridded landings data to identify areas where commercial fishing activity would be affected by oiling. Exhibit 4-6 below provides a visual representation of the oiling data overlaid on the gridded revenue data for the mitigated 200,000-barrel spring oiling scenario off the coast of Delaware.

EXHIBIT 4-6. ILLUSTRATION OF ARCGIS OVERLAY ANALYSIS



Closure Indicator (C_t)

A commercial fishing grid cell was assumed to be closed if the oiling indicator was equal to 1. The duration of the closure for the grid cell was determined based on the overall size of the modeled spill scenario. Due to the uncertainty in closure duration, this analysis utilized a range of closure durations for most spill sizes. The ranges chosen for each spill size category were based on a review of fishery closures implemented in response to past oil spills. Exhibit 4-7 presents the results of the review, and Exhibit 4-8 details the closure duration ranges by spill scenario size used in this analysis. The basis of the assumed closure durations is as follows:

- ***126-barrel spills:*** The analysis assumes a closure duration of one to three weeks. The low end of this range is roughly consistent with the duration of the fishery closure for the 2018 Bristol Bay spill (19 barrels, as shown in Exhibit 4-7 below). The high end of the range assumes that the closure for a 26-barrel spill would be shorter in duration than the closure for the 2,934-barrel Refugio spill (39 days).
- ***2,240-barrel spills:*** This analysis considered the closure durations for the *Selendang Ayu*, *North Cape*, and Refugio spills. Because the marine environments associated with the latter two are more similar to the environment off Delaware's coast than the marine environment where the *Selendang Ayu* spill occurred (in the Aleutian Islands), the assumed range for the 2,240-barrel spills is based on the closure durations associated with the North Cape and Refugio spills.
- ***200,000-barrel spills***: The high end of the assumed three- to 12-month range is consistent with the duration of closure associated with the Aegean Sea spill. Because the 200,000-barrel spills in this analysis are less than half the size of the Aegean Sea spill or the *Sea Empress* spill (the largest spills in Exhibit 4-7), this analysis assumes that that the low end would be lower than the closure duration for either of these spills. To derive the low-end duration value, this analysis scaled the 200-day closure duration for the Sea Empress spill, assuming a linear relationship between spill volume and closure duration. This process yielded a closure duration of approximately three months.
- ***900,000-barrel spills:*** For both the lower and upper bound scenarios for the unmitigated 900,000-barrel spill scenario, the analysis assumes a closure duration of 12 months. Based on a review of the spills included in Exhibit 4-5, particularly the *Deepwater Horizon* oil spill of 2010, this represents a reasonable worst-case assumption for a blowout spill of such a size.

EXHIBIT 4-7. HISTORICAL CLOSURE DURATIONS

SPILL	LOCATION	YEAR	SPILL SIZE (BARRELS)	CLOSURE DURATION
Selendang Ayu[1]	Aleutian Islands (Alaska)	2004	8,330	284 days
Bristol Bay[2]	Alaska	2018	19	6 days
Aegean Sea (Galacian Fisheries Council)[3]	Europe	1992	478,884	>12 months
Sea Empress[4]	Wales	1996	492,566	200 days
North Cape[5]	Rhode Island	1996	19,714	5 months
Refugio[6]	California	2015	2,934	39 days
Deepwater Horizon[7]	Gulf of Mexico	2010	4,900,000	Between 10 months and over 1 year

Notes:
1. Wood & Associates (2005).
2. Salomone et al. (2019).
3. Moller et al. (1999).
4. Leonard et al. (1999).
5. NOAA. Incident News: Barge North Cape, https://incidentnews.noaa.gov/incident/7121
6. California Department of Fish and Wildlife et al. (2020).
7. Carroll et al. (2016).

As an example, if a grid cell were to experience oiling above the threshold in the spring 2,240-barrel oil spill scenario, the analysis would assume that commercial fishing would be closed in this area for one month in the lower bound scenario and five months in the upper bound scenario. It may be the case that closure durations would vary between oiled areas for the same spill. However, due to difficulties in modeling this type of closure implementation and limited data on the relationship between spill size and closure duration, this analysis assumes that all oiled grid cells above the threshold value of 0.1 g/m^2 remain closed for the same amount of time.

EXHIBIT 4-8. ANALYSIS COMMERCIAL FISHERY CLOSURE DURATIONS

SCENARIO SPILL SIZE	CLOSURE DURATION		UNIT
	LOWER BOUND	UPPER BOUND	
Unmitigated 126 barrels	1	3	Weeks
Unmitigated 2,240 barrels	1	5	Months
Mitigated 200K barrels	3	12	Months
Unmitigated 200K barrels	3	12	Months
Unmitigated 900K barrels	12	12	Months

RESULTS

Applying the data and methods described above, the estimated lost commercial fishing revenues for each spill scenario are presented in Exhibits 4-9 and 4-10. For each spill scenario, the analysis estimated lower and upper bound lost revenue impacts. These ranges are determined by the closure duration ranges for each spill size. The red bars in Exhibits 4-9 and 4-10 show the relative magnitude of impacts across spill scenarios (i.e., the red bar for the highest-impact scenario fills an entire cell in each exhibit, and red bars for other cells are proportionately smaller based on the estimated impacts).

EXHIBIT 4-9. LOST COMMERCIAL FISHING REVENUE - LOWER BOUND ESTIMATES

Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$720,000	$90,000	$270,000	$0
	Surface	Unmitigated 200,000bbl	$3,670,000	$3,380,000	$2,190,000	$560,000
	Surface	Mitigated 200,000bbl	$3,510,000	$3,180,000	$1,880,000	$530,000
	Subsurface	Unmitigated 900,000bbl	$11,630,000	$11,630,000	$11,260,000	$11,580,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$10,000	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$60,000	$30,000	$2,160,000	$1,500,000
	Surface	Mitigated 200,000bbl	$60,000	$10,000	$30,000	$20,000
	Subsurface	Unmitigated 900,000bbl	$11,450,000	$11,370,000	$11,340,000	$11,510,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$10,000	$3,300,000	$60,000	$0
	Surface	Mitigated 200,000bbl	$0	$2,280,000	$50,000	$0
	Subsurface	Unmitigated 900,000bbl	$11,350,000	$490,000	$1,300,000	$610,000

EXHIBIT 4-10. LOST COMMERCIAL FISHING REVENUE - UPPER BOUND ESTIMATES

Spill Location	Spill Type	Spill Scenario	Spring	Summer	Fall	Winter
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$3,240,000	$460,000	$690,000	$0
	Surface	Unmitigated 200,000bbl	$11,190,000	$11,320,000	$9,360,000	$4,000,000
	Surface	Mitigated 200,000bbl	$10,690,000	$10,670,000	$8,030,000	$3,840,000
	Subsurface	Unmitigated 900,000bbl	$11,630,000	$11,630,000	$11,260,000	$11,580,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$40,000	$50,000	$0	$50,000
	Surface	Unmitigated 200,000bbl	$190,000	$90,000	$9,220,000	$10,820,000
	Surface	Mitigated 200,000bbl	$180,000	$20,000	$130,000	$130,000
	Subsurface	Unmitigated 900,000bbl	$11,450,000	$11,370,000	$11,340,000	$11,510,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$10,000	$0
	Surface	Unmitigated 200,000bbl	$20,000	$11,070,000	$260,000	$0
	Surface	Mitigated 200,000bbl	$0	$7,630,000	$220,000	$0
	Subsurface	Unmitigated 900,000bbl	$11,350,000	$490,000	$1,300,000	$610,000

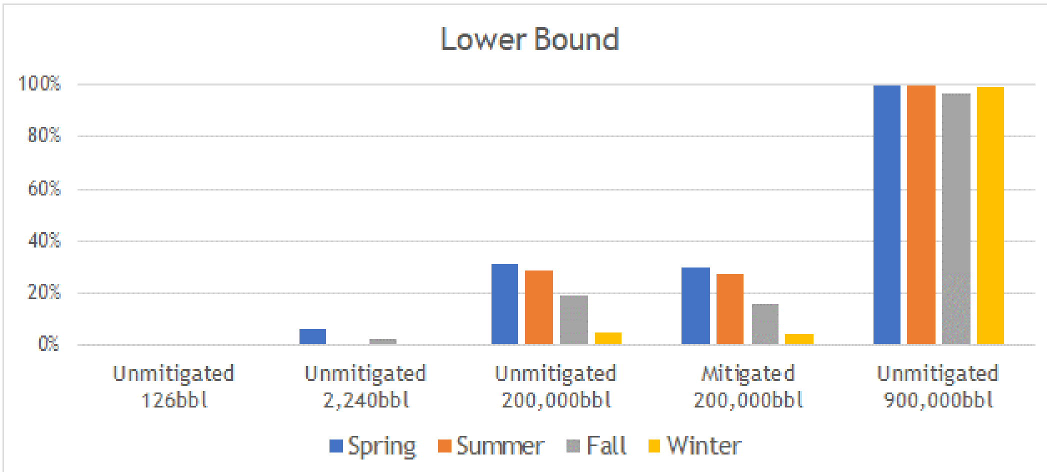
For each spill location, this analysis presents only the impacts to the Delaware commercial fishery. As shown in Exhibits 4-9 and 4-10, impacts are more significant for the spill scenarios occurring off the coast of Delaware than for the spills occurring off New Jersey or Virginia. This reflects the spatial distribution of surface oiling relative to high-intensity fishing areas in Delaware's coastal waters. A large portion of Delaware's commercial fishing activity occurs at the mouth of the Delaware Bay as well as the area directly to the east of the bay. All of the surface oil scenarios for Delaware affect these areas to some degree while some of the scenarios for other spill locations may not impact any of the highest density commercial fishing grid cells. As an example, as shown in Exhibits 4-9 and 4-10, there are several surface oiling scenarios for the Virginia spill location that do not result in any impacts to Delaware's commercial fishery.

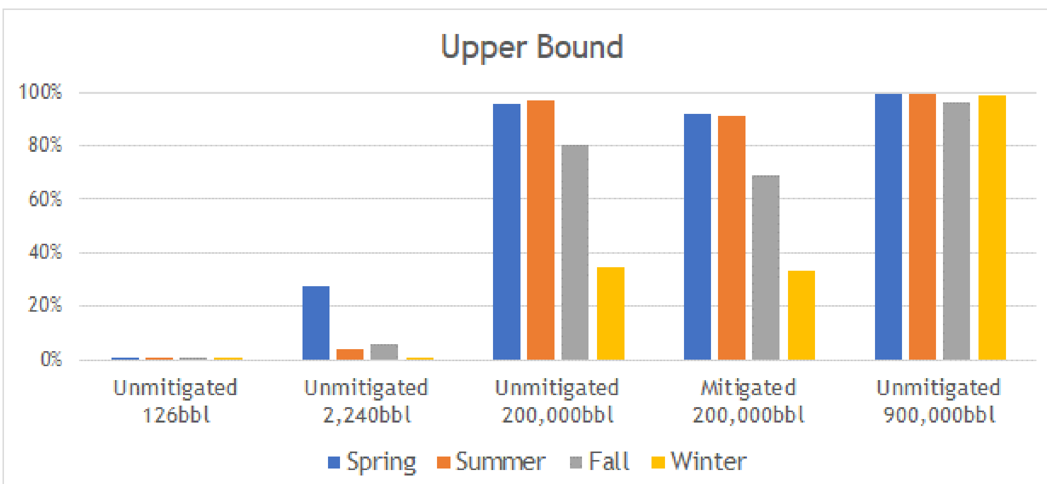
Estimated lost commercial fishing revenues also tend to be highest for spills occurring during the spring and summer. This is due to the timing of the open commercial fishing seasons for Delaware's more profitable fisheries (e.g., blue crab, which is open from the beginning of March through November). For the unmitigated 200,000-barrel scenarios off the coast of New Jersey, however, lost revenues are higher for spills occurring in the fall and winter than for spills occurring in the spring and summer. This reflects how the worst-case spill is defined for each scenario. As described in Chapter 2, the specification for the worst-case scenario is based on the maximum shoreline oiled across the entire Mid-Atlantic region rather than the maximum shoreline oiling on Delaware's coast. In the case of the unmitigated 200,000-barrel spring and summer spills off the coast of New Jersey, the maximum shoreline oiling is projected when currents and the wind carry the oil northward, causing significant oiling along New Jersey and southern Long Island, but no oiling around Delaware's coast.

In general, the larger unmitigated spills in each location result in more significant commercial fishing impacts than the smaller unmitigated spills. This is due to more widespread oiling in Delaware coastal waters as well as the extended, multi-season, or even year-long, closure durations. For Virginia spills, however, the impacts associated with the 900,000-barrel summer blowout scenario are estimated to be less than impacts for both 200,000-barrel scenarios (mitigated and unmitigated). This also reflects how the worst-case spill is defined, as well as the assumed spill location for the blowout scenarios relative to the surface scenarios. Because the blowout scenarios are assumed to occur far offshore, the worst-case conditions for these spills differ from those for surface spills occurring closer to shore. For the summer blowout scenario off the coast of Virginia, the conditions resulting in the worst case (defined as maximum shoreline oiling) push the spilled oil southward, causing significant oiling along and near the Virginia and North Carolina coasts, but result in minimal oiling off the coast of Delaware. In contrast, the worst case for the surface spills is under conditions that push spilled oil northward, toward the fishing grounds of Delaware's commercial fishing industry. For additional information on the spill modeling assumptions, see RPS (2021).

For additional perspective on commercial fishing revenue losses, Exhibit 4-11 shows these losses as a percentage of annual revenues for Delaware's commercial fishery. The exhibit highlights that larger spills occurring during the spring and summer could lead to losses equal to nearly a full year's revenues for the industry under the upper bound assumptions (and lower bound for the 900,000-barrel blowout scenario).

EXHIBIT 4-11. LOST COMMERCIAL FISHING REVENUE (DE SPILL LOCATION) AS A PERCENT OF ANNUAL BASELINE REVENUES





KEY UNCERTAINTIES

The analysis presented in this chapter relies on the best available information on Delaware's commercial fishery and the trajectory of spilled oil associated with each spill scenario. Nevertheless, the impact estimates presented here are subject to a number of uncertainties, the most significant of which are as follows:

- The duration of fishery closures can vary significantly across spills of a given magnitude. The closure durations applied in this analysis are based on the limited information on closures available from past spills and may not be applicable in all cases.

- The analysis implicitly assumes that the commercial fishing industry would not be able defer fishing to later in the season in the event of a spill, or concentrate its landings into a shorter portion of the season. Such adaptations could reduce impacts to the industry.
- The analysis also assumes that the commercial fishing industry would not seek alternative locations to catch fish in the event of a spill. Such a mitigating strategy could be somewhat effective for finfish. This strategy may not be feasible for shellfish, given that they are concentrated along the coast and lack the mobility of finfish.

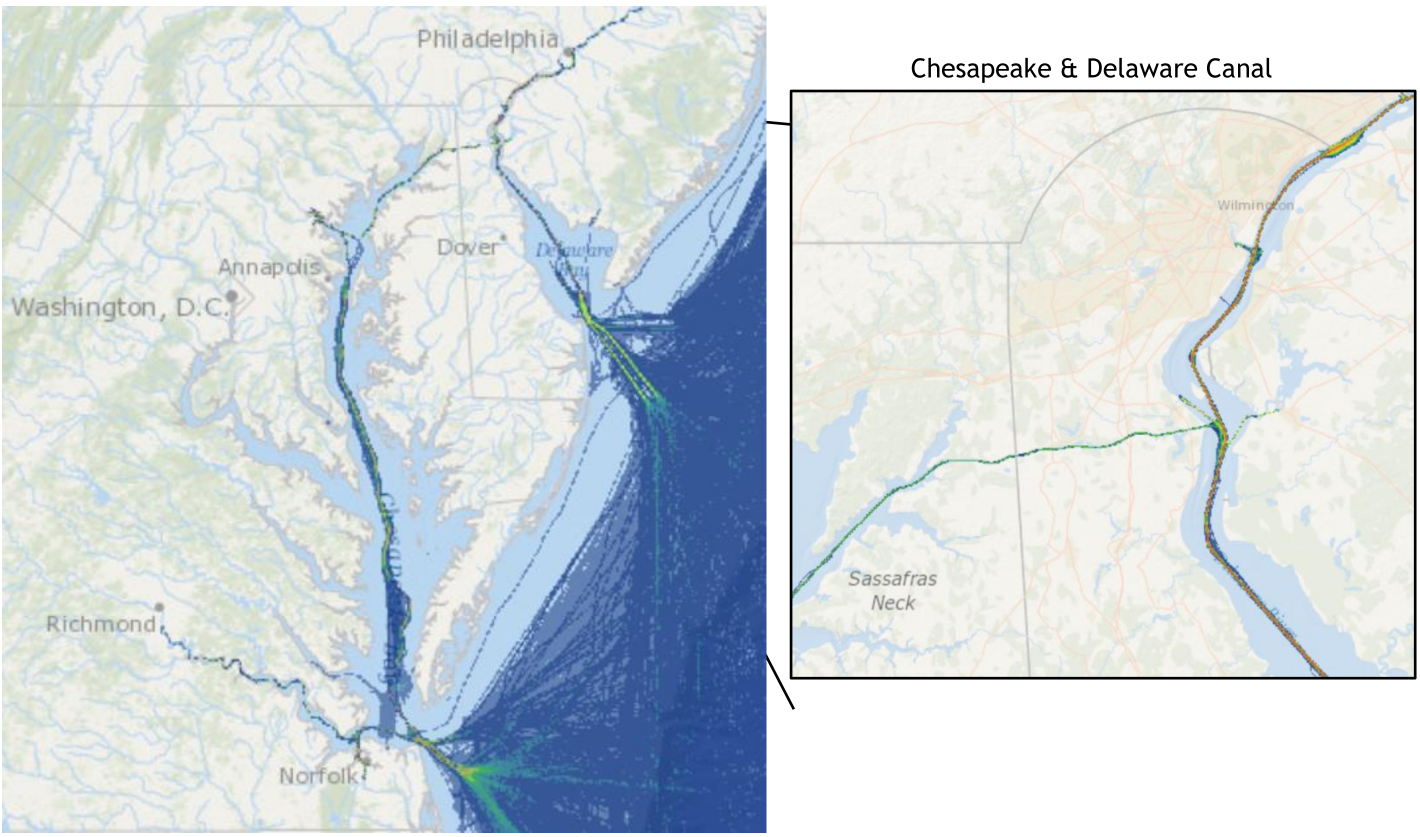
CHAPTER 5 | COMMERCIAL SHIPPING

Oil spills and the resulting surface oil sheens present unique challenges to the commercial shipping industry. Ships passing through affected waters can carry oil with them along their route, potentially contaminating ports or sensitive environmental areas. Travelling through surface sheens could also cause damage to vessel function, and large enough quantities could produce hazardous fumes that may pose a health risk to crewmembers. To avoid these potential risks in the immediate aftermath of a spill, commercial shipping vessels may choose to either 1) delay progress on their route until the oil slick is removed or 2) reroute their path to circumnavigate the polluted area. Both avoidance strategies can result in significant delays to commercial shipping traffic. Even small spills can prevent commercial traffic from travelling through affected shipping lanes if travel restrictions or temporary closures are imposed on affected areas. Whether a vessel remains in place to await the clearance of oil, or decides to seek an alternate route, it will still incur fuel and other operating costs (e.g., crew wages, maintenance, etc.).

This analysis examines the effects of the oil spill scenarios described in Chapter 2 on commercial shipping traffic passing through Delaware ports, specifically the Port of Wilmington and the Port of New Castle. To access these ports, commercial vessels must travel into the Delaware Bay, either through the strait that links the Bay to the Atlantic Ocean, or through the Chesapeake and Delaware (C&D) Canal that connects the Delaware and Chesapeake Bays, as shown in Exhibit 5-1. To the degree that the spill scenarios defined in Chapter 2 lead to surface oiling in the area leading into the Delaware Bay from the Atlantic Ocean, this analysis examines whether vessel traffic (1) remains in place and waits for the surface oil to disperse, or (2) diverts course towards the Chesapeake Bay in order to access Delaware ports via the C&D Canal. This analysis estimates the costs associated with these vessel delays and diversions under a given spill scenario, inclusive of vessels' fuel, operating, and pilotage costs.

The following sections describe the data and methods applied in this analysis and the estimated cost impacts derived from these methods. The first portion of the analysis presents the data used for determining the number of vessels potentially impacted by the various spill scenarios. The analysis then integrates this information with the oil spill modeling outputs described in Chapter 2 and unit vessel operating cost data to estimate the incremental costs to commercial vessels traveling to or from Delaware ports for each spill scenario. This information is presented separately for vessels likely to reroute (diversion costs) and vessels likely to wait until spilled oil is sufficiently clear (delay costs).

EXHIBIT 5-1. SHIPPING TRAFFIC NEAR DELAWARE PORTS



Note: Red and yellow represent higher vessel traffic. Green represents lighter vessel traffic.
Source: Mid-Atlantic Ocean Data Portal. Data shown represent annual vessel transits for 2019.

COUNT OF VESSELS DELAYED OR DIVERTED

The first step in assessing the cost impacts to delayed and diverted commercial vessels involves calculating the total number of vessels potentially affected by a spill. The vessels are then divided into categories based on port of origin or destination, whether they would delay in place or divert their route, and the ship type (i.e. bulker, container, tanker).

The U.S. Army Corps of Engineers (USACE) publishes data on annual vessel entrances and clearances to major U.S. ports. These data also indicate the port of origin for inbound vessels and port of destination for outbound vessels. For the purposes of this analysis, these origin and destination ports are classified based on location relative to the Delaware Bay, falling into one of four categories:

- **Delaware Bay:** Ports within the Delaware Bay or up the Delaware River, further categorized by state (e.g., Wilmington, Philadelphia, and Camden).
- **Chesapeake Bay:** Ports within the Chesapeake Bay or upriver from the Chesapeake Bay (e.g., Baltimore, Norfolk, and Washington, DC).

- **North of Delaware Bay:** Vessels expected to arrive from or depart to the north relative to the Delaware Bay (e.g., New York and Reykjavik).
- **South of Delaware Bay:** Vessels expected to arrive from or depart to the south relative to the Delaware Bay (e.g., Miami, Los Angeles, South America, and Asia).[27]

Using this categorization, the final vessel count includes all vessels traveling to or from Delaware ports (excluding ports in PA and NJ), except those traveling between Delaware Bay ports[28] and from Delaware Bay ports to Chesapeake Bay ports.[29]

The USACE data on vessel entrances and clearances lists the draft measurement for each vessel. The draft of a vessel represents the vertical distance between the waterline and the bottom of the hull, indicating the minimum water depth through which a vessel can safely navigate. The C&D Canal has a depth of approximately 35 feet, meaning vessels with a draft greater than 35 feet cannot physically access the Canal. Furthermore, the pilots tasked with operating vessels using the Canal require at least a two-foot clearance between the bottom of the Canal and bottom of the hull, meaning that vessels must have a draft of less than 33 feet to traverse the Canal. For the purposes of this analysis, it is assumed that all vessels capable of using the C&D Canal will elect to do so in the event of an oil spill blocking the entrance to the Delaware Bay, while those vessels unable to access the Canal will remain in the Atlantic Ocean or in port until the surface oiling is cleared. The USACE data also indicates whether a vessel is a container ship, a bulker, or a tanker.

The USACE data for 2018 indicate that of the approximately 173,000 entrances and clearances of commercial vessels to and from U.S. ports each year, 799 inbound and outbound voyages involved Delaware ports, excluding trips directly between Delaware ports and Chesapeake ports. Exhibit 5-2 provides a further breakdown of inbound and outbound vessels by whether they would divert or delay their route (based on vessel draft) and the type of commercial vessel.

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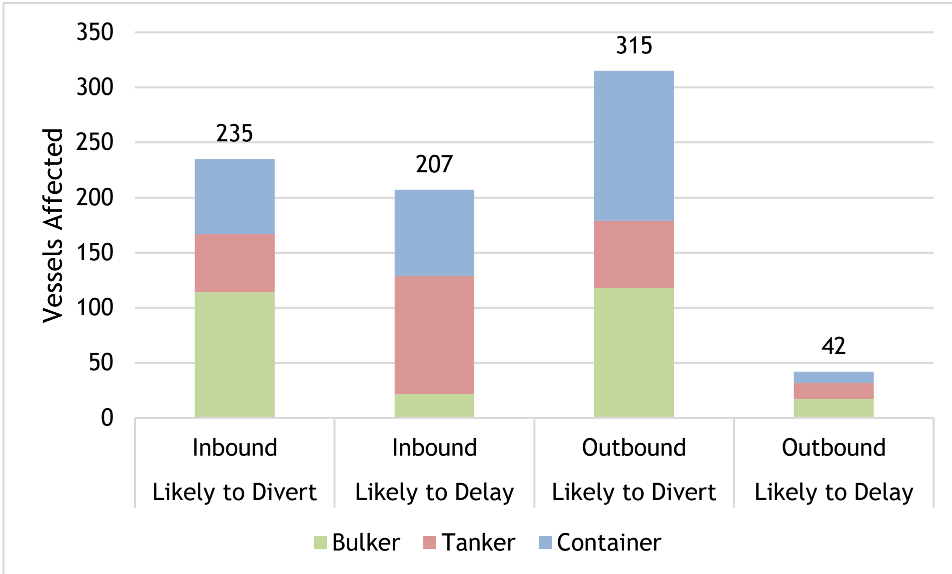
27 Vessels bound from east Asia are assumed to travel to Delaware from the south (i.e., via the Panama Canal).

28 These voyages would not be affected by surface oiling of the Delaware Bay entrance.

29 These voyages would most likely not be affected by surface oiling of the Delaware Bay entrance since vessels would enter the Atlantic Ocean from the Chesapeake Bay.

EXHIBIT 5-2. NUMBER OF INBOUND AND OUTBOUND VESSEL VOYAGES THROUGH DELAWARE PORTS EACH YEAR



Note: Each bar in this graph shows the tally of vessels passing through Delaware ports based on whether they are inbound or outbound vessels and whether they are likely to be delayed by a spill or divert due to a spill. The delay/divert distinction is based on whether the draft of the vessel is less than 33 feet, enabling it to travel through the Chesapeake and Delaware Canal.

While Exhibit 5-2 shows the number of annual vessel voyages through the Delaware ports, each spill is only expected to impact commercial shipping traffic for a matter of days. The annual totals are therefore converted to daily values in order to calculate the number of affected vessels for each spill scenario.

CALCULATING INCREASED COSTS

For each vessel diverted or delayed from its original route, costs are incurred due to the additional consumption of fuel, the prolonged operations of the vessel, and the pilotage costs associated with diverting from the original route. The incremental fuel consumption, operating, and pilotage costs are largely dependent on the vessel size and design, vessel speed, duration of delay or alternate voyage, and type and price of fuel used. The methods for estimating delay costs and diversion costs are presented below.

ESTIMATING DURATION OF BLOCKAGE BY OILING SCENARIO

The duration of the blockage to the entrance to Delaware Bay affects shipping costs for vessels that divert and proceed on their voyage following a different route as well as vessels that temporarily halt their voyage and are therefore delayed. This analysis estimates the blockage duration by comparing each modeled oil spill scenario with similar historic spills and their corresponding effects on commercial shipping lanes. Due to the significant variability across the historic spills used for comparison, this analysis specifies lower and upper bound estimates. While the lower and upper bound values capture the likely range of outcomes based on similar historic spills, it should be noted that a multitude of factors can influence how long an area is closed to commercial vessel traffic, including spill response effectiveness, proximity to shipping lanes, ocean currents, and weather conditions. This variation is evidenced in Exhibit 5-3, which shows which spill sizes and locations would likely block the entrance to the Delaware Bay and result in costs to the commercial shipping traffic, based on the oil spill modeling summarized in Chapter 2. For spill scenarios under which the entrance to Delaware Bay is not blocked, this analysis assumes no vessel diversions or delays and no costs to the commercial shipping sector.

EXHIBIT 5-3. DELAWARE BAY BLOCKAGE BY SPILL SCENARIO AND SEASON

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Blocked	Blocked	Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Blocked	Blocked	Blocked	Not Blocked
	Surface	Mitigated 200,000bbl	Blocked	Blocked	Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	Blocked	Blocked	Blocked	Blocked
New Jersey	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Blocked
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	Blocked	Blocked	Blocked	Blocked
Virginia	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	Blocked	Not Blocked	Not Blocked
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	Blocked	Not Blocked	Not Blocked	Not Blocked

Exhibit 5-4 shows the lower bound and upper bound blockage durations for each spill size category specified in Chapter 2 and notes the historical spills that informed the specification of the lower bound and upper bound values. These closure duration boundaries only apply for spill scenarios that would likely block the entrance to the Delaware Bay, based on the oil spill modelling summarized in Chapter 2.

EXHIBIT 5-4. DURATION OF BLOCKAGE BY SPILL SIZE CATEGORY

SPILL SCENARIO (BBL)	LOWER BOUND ESTIMATE	UPPER BOUND ESTIMATE	HISTORICAL SPILLS INFORMING LOWER BOUND AND UPPER BOUND
Low (126)	0 days	0 days	No information on commercial traffic restrictions for spills of this size. Also, the entrance to Delaware Bay is not projected to be blocked under these scenarios.
Medium (2,240)	2 days	5 days	The specified range based on three spills: • 2014 Texas City Y spill; 4,000 barrels spilled; commercial vessel traffic restrictions for 5 days (given greatest weight for upper bound).[1] • 2004 *Athos* spill; 6,310 barrels spilled; commercial vessel traffic restrictions for 2-8 days.[2] • 2008 *Tintomara* spill; 9,976 barrels spilled; commercial vessel traffic restrictions for 6 days.[3]
High Unmitigated (200,000)	4 days	7 days	The specified duration based on the 1989 *Exxon Valdez* spill of 257,000 barrels. The spill resulted in commercial vessel traffic restrictions for 4 days.[4]
High Mitigated (200,000)	3 days	6 days	Based on, though not equal to, duration of blockage for the high unmitigated spills.
Well Blowout (900,000)	7 days	9 days	The specified duration based on the 2010 *Deepwater Horizon* spill of 4.9 million barrels. The spill resulted in commercial vessel traffic restrictions for 7 to 9 days.[5]

Sources:
1. Kruse and Protopapas (2014).
2. NOAA (2004).
3. Charpentier (2008).
4. U.S. Coast Guard (1993).
5. U.S. Army Corps of Engineers (2011).

Low-Volume Spill Scenarios

Based on the oil spill modeling described in Chapter 2, the low-volume (126-barrel) spill scenarios are not expected to result in an oil slick that impedes vessel traffic entering or exiting Delaware Bay in any season or spill location. It is possible that some vessels could be exposed to low surface oil concentrations, but this is not anticipated to cause a vessel to significantly delay or divert its course.

Medium-Volume Spill Scenarios

The worst-case medium-level spill scenarios involving 2,240 barrels are estimated to result in two to five days of blockage of the Delaware Bay entrance. This range is based on the three historic spills listed in Exhibit 5-4: Texas City Y, M/T *Athos* I, and the *Tintomara* spill. For the lower bound estimate of two days, this analysis draws on the experience of the M/T *Athos* I spill. Two days after the spill, the shipping lane was opened to limited traffic; after six days, to most traffic but with draft restrictions; after eight days, with no restrictions. The upper bound is based on all three spills, though the Texas City Y spill was given the greatest weight among the three. The Texas City Y spill, which took place near the entrance to the Galveston Bay, best reflects the volume and geography of the medium-volume spill scenarios examined in this analysis and led to five days of vessel traffic restrictions. Although the *Tintomara* and *Athos I* spills resulted in slightly longer restrictions, six days and eight days,[30] respectively, these were both riverine spills and therefore may not be as transferrable to the marine environment outside Delaware Bay as the Texas City Y spill. In addition, the spill volumes for the *Athos I* and *Tintomara* spills exceeded the medium-volume spill amounts examined in this analysis by factors of three and four, respectively.

High-Volume, Unmitigated Spill Scenarios

The assumed blockage duration for the high-volume, unmitigated scenarios is based on the 1989 *Exxon Valdez* spill, which was similar in volume to the high-volume scenarios examined in this analysis. According to the Federal On Scene Coordinator's (FOSC's) Report (USCG 1993), the total shipping-related closures lasted approximately four days. However, the report notes that in hindsight the FOSC would have preferred not to reopen as quickly. The spill cleanup also benefitted from favorable weather conditions, making the four-day value appropriate for a lower bound (USCG 1993). Since no other spills can be used for comparison, the upper bound of seven days was established based on the range of three days between lower and upper bounds for medium-sized spills.

High-Volume, Mitigated Spill Scenarios

The blockage duration for the high-volume mitigated spill scenarios is expected to be lower than that of the unmitigated high-volume spill scenarios but higher than that of the medium-volume spill scenarios. This results in a lower bound blockage duration estimate of three days and an upper bound estimate of six days. Ultimately, the mitigation efforts associated with the mitigated scenario are expected to reduce the blockage duration by one day.

Well Blowout Scenarios

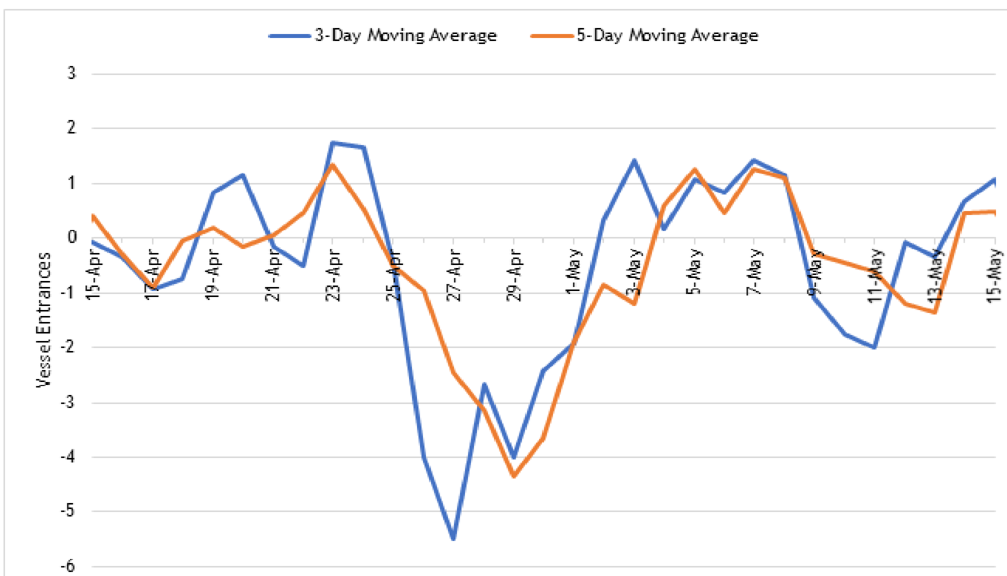
The estimated closure duration for the well blowout scenarios is directly based on the 2010 *Deepwater Horizon* well blowout event that took place in the Gulf of Mexico. While no definitive estimates have been released regarding the closure of ports or

[30] The eight days for the *Athos* spill is the time before all vessel traffic was open. As noted above, the Delaware River was partially opened after two days and further opened to most traffic after six days.

shipping lanes, the effect on commercial shipping activity can be estimated by examining changes in vessel entrances and clearances from the ports surrounding the Gulf of Mexico.

Using the USACE dataset described above containing data on total vessel entrances and clearances to U.S. ports, this analysis examined changes in shipping activity in the aftermath of the *Deepwater Horizon* spill. Focusing on the Port of New Orleans, likely the largest port significantly affected by the event, a noticeable drop in vessel entrances is apparent in the 2010 data compared to a composite of the four surrounding years of 2008-2009 and 2011-2012. While total vessel traffic from April to July of 2010 was lower compared to the same period in 2008, 2009, 2011, and 2012, this approach focuses on vessel delays in the immediate, short-term aftermath of the spill by comparing average daily vessel entrances after April 20th, 2010, with the average vessel entrances in the same time period in the four surrounding years. To smooth out day-to-day variation in entrances to the port, this analysis calculated vessel entrances for a given day as a three-day moving average and as a five-day moving average. For example, the three-day moving average for April 26, was based on daily data for April 25, April 26, and April 27. Using a three-day moving average, a delay of seven days in vessel entrances to the Port of New Orleans becomes apparent (see the blue line dip below 0 for seven days in Exhibit 5-5); using a five-day moving average, a delay of nine days.

EXHIBIT 5-5. PORT OF NEW ORLEANS VESSEL ENTRANCES IN 2010 RELATIVE TO AVERAGE OF 2008, 2009, 2011, AND 2012[31]



Each line in the graph represents the difference between daily vessel entrances in 2010 and average daily vessel entrances for 2008, 2009, 2011, and 2012.

[31] The *Deepwater Horizon* spill began on April 20, 2010; however, the data indicates that the oil did not come close enough to affect commercial traffic near the Port of New Orleans, about 100 miles away, until April 25, several days later.

CALCULATING VESSEL DELAY COSTS

In the event that an oil spill blocks entry into and exit from Delaware Bay, the costs of delay include the fuel and operating costs associated with the additional time of outbound vessels at port or inbound vessels at sea, since these vessels are expected to continue their original route once the surface oil blockage is cleared. Because delayed vessels will ultimately resume their original route, there are no additional pilotage costs associated with vessel delays. Each of these components of vessel delay costs is described below.

Vessel Delay: Fuel Costs

To calculate fuel consumption costs, this analysis uses the statistical fuel consumption model from Le et al. (2020), which incorporates a vessel's speed, size, and voyage time to calculate the total fuel consumption of a ship's voyage in metric tonnes. The equation below shows the details of this calculation.

$$F = (\alpha_g \times t \times s^3) + (\beta_g \times t)$$

Where F = a vessel's fuel consumption;

α_g = an estimated parameter for vessels in size group g, measured in twenty-foot equivalent units (TEU) (see Exhibit 5-6);

t = time, measured in days;

s = vessel speed, measured in knots, and

β_g = an estimated parameter for vessels in size group g, measured in twenty-foot equivalent units (TEU) (see Exhibit 5-6);

For the time of delay (t), the analysis applies the estimates presented above in Exhibit 5-4. For vessel speed, this analysis assumes that ships at sea travel at a speed of 5 knots to maintain maneuverability; at port, a ship typically runs the auxiliary engine to maintain onboard electronic systems at a power level roughly equivalent to a speed of 3 knots (California Air Resources Board 2011). Note that the at-port speed equivalent of 3 knots is a rough approximation to capture fuel consumption while docked, and may vary by engine, cargo, time of day, and other factors.

To apply the appropriate α_g and β_g values from Exhibit 5-6 to a given vessel, TEU was specified for each vessel. Although TEU data are not readily available for all vessels passing through Delaware ports, each vessel size roughly corresponds to a deadweight tonnage (DWT) measurement, as reported at yieldstreet.com (2021). Using the relationship between DWT and TEU calculated in Abramowski et al. (2018), a range of TEU values is estimated for each vessel size. This range is used in the fuel consumption calculation from Le et al. (2020), with diverted vessels with a TEU equivalent of <3,000 using Le et al.'s (2020) "Group 1" model and delayed vessels with a TEU equivalent of 3,000 to 5,999 using the Le et al. "Group 2" model for vessel fuel consumption.[32]

[32] Although the statistical parameters shown in Exhibit 5-6 cover four groups of vessels defined according to their TEU, the vessel data for Delaware ports indicate that the vessels using these ports are limited to Groups 1 and 2.

EXHIBIT 5-6. STATISTICAL PARAMETERS FOR ESTIMATION OF VESSEL FUEL CONSUMPTION

ESTIMATION GROUP	TWENTY-FOOT EQUIVALENT UNITS (TEU) RANGE	ALPHA (α)	BETA (β)
Group 1	<3,000	0.0072	10.8592
Group 2	3,000 - 5,999	0.0101	20.2406
Group 3	5,999 - 7,999	0.012	31.938
Group 4	7,999 - 11,999	0.0141	32.1584
Group 5	11,999 - 14,999	0.018	32.2535
Source: Le et al. (2020)			

As the final step in estimating the increase in fuel costs, this analysis applies the average price of Very Low Sulphur Fuel Oil (VLSFO) to the estimated increase in fuel consumption derived from the approach outlined above. As of January 1, 2020, the International Maritime Organization (IMO) requires that all commercial vessels limit the sulfur content in their fuel oil to a maximum of 0.5 percent. VLSFO is expected to become a popular choice to comply with the IMO rules. The average price of VLSFO for the year 2020 from the heavily trafficked Port of Houston was $340.41/Mt (adjusted to year 2019$) (shipandbunker.com 2020).

Based on the approach above, the average daily fuel cost for vessels delayed at sea is approximately $7,320 while the average daily fuel cost for vessels delayed at port is $6,980.

Vessel Delay: Operational Costs

To calculate the operational cost component of vessel delay costs, the analysis uses data from a report by Moore Stephens (2017) that includes daily operating costs for a multitude of vessel types and sizes. Operating costs include payment of crew, usage of materials and food stores, repairs & maintenance, and other costs incurred daily. The costs reported by Moore Stephens exclude the costs of fuel.

Based on the Moore Stephens (2017) data, this analysis calculates the average daily operating cost for each vessel type and size category, shown in Exhibit 5-7, averaging values where multiple vessel sizes fit into one category. For example, the Handysize bulker is the only bulker-type vessel that is expected to fit through the Canal, so the operating cost of bulker vessels that fit the Canal (i.e., diverted) is assumed to equal the operating cost of the Handysize bulker. The Handymax and Panamax bulker sizes would not fit through the Canal, but are still expected to use Delaware ports, so the average operating cost of these two size categories is used for all delayed bulkers. The Capesize bulker is too large to dock at Delaware ports, so its operating costs are not included in the analysis. The resulting average operating costs of delayed vessels, by type, are weighted by the proportion of each delayed vessel type to generate a weighted average of daily operating costs for all vessels too large to fit through the Canal. The average daily operating cost for all vessels delayed comes out to $6,921 (rounded to $7,000 in Exhibit 5-7). An identical calculation is done for smaller vessels, such as the Handysize bulker, that would elect to divert through the Canal and amounts to an average daily operating cost for all vessels diverted of $5,506 (rounded to $5,500 in Exhibit 5-7).

EXHIBIT 5-7. AVERAGE OPERATING COSTS FOR DIVERTED AND DELAYED VESSELS (YEAR 2019$)

VESSELS DIVERTING OR DELAYING	VESSEL TYPE	AVERAGE DAILY COSTS	ANNUAL COUNT OF VESSEL TYPE (PERCENT OF TOTAL)
Divert (Draft <33 feet)	Bulker	$5,200	232 (42%)
	Tanker	$7,800	114 (37%)
	Container	$4,600	204 (21%)
	Weighted Average	**$5,500**	**550**
Delay (Draft >=33 feet)	Bulker	$5,800	39 (16%)
	Tanker	$8,400	122 (35%)
	Container	$5,400	88 (49%)
	Weighted Average	**$6,900**	**249**

Applying the daily operating cost to the average duration of delay, this analysis estimates the total delay cost per vessel. This value is then multiplied by the number of vessels delayed to calculate the total delay costs of a spill.

CALCULATING VESSEL DIVERSION COSTS

The cost calculation for diverted vessels bears many similarities to the calculation described above for delayed vessel costs, primarily the focus on the fuel consumption and operating costs of affected vessels. However, because diverted vessels do not follow their original route, the analysis calculates the additional fuel consumption, operating, and pilotage costs of diversion relative to costs associated with the original route. Since what is considered to be the original or standard route varies based on the direction in which a vessel is traveling, this analysis uses weighted averages to capture variation in alternate route length (i.e., diverted vessels arriving from the North would travel farther than those arriving from the South). The additional fuel, operating, and pilotage costs can be multiplied by the number of vessels affected each day and the number of days of blockage, represented below:

$$C_{div} = (DIV_v - S_v) \times v \times d$$

Where C_{div} = Total incremental costs of diversion;

DIV_v = Costs per vessel for the diverted route;

S_v = Costs per vessel for the standard route;

v = number of vessels affected per day, and

d = days of blockage

To calculate the fuel, operation, and pilotage costs of the standard and diverted routes, the trips are broken into several voyage "legs" based on how the routes vary. The four legs assessed, as well as their estimated distance, speed, and resulting fuel consumption, are as follows:

- **Delaware Bay to C&D Canal:** Calculated as the length from the Delaware Bay entrance to the C&D Canal. Estimated to be 60 miles long, with an average speed of 15 knots and calculated fuel consumption of 5 Mt.
- **Chesapeake Bay to C&D Canal:** Calculated as the distance from the Chesapeake Bay entrance (around Norfolk) to the C&D Canal (around Elk Forest Wildlife Management Area). Estimated to be 190 miles, with an average speed of 15 knots and calculated fuel consumption of 16 Mt.
- **Delaware Bay to Chesapeake Bay:** Calculated as the distance from the entrances of the Delaware and Chesapeake Bays. Estimated to be 140 miles long, with an average speed of 15 knots and calculated fuel consumption of 12 Mt.
- **C&D Canal:** The Canal is roughly 17 miles long, with an average speed of 7 knots and calculated fuel consumption of 1 Mt.

Below, Exhibit 5-8 details the standard and diverted routes for vessels traveling between Delaware ports and points north as well as between Delaware ports and points south.

EXHIBIT 5-8. DISTANCE FOR AFFECTED LEGS OF VESSEL TRIPS

DIRECTION	ROUTE	LEGS TRAVELED[1]	LEG DURATION (HOURS)	ESTIMATED FUEL CONSUMPTION (MT)
Between DE Ports and Points **North**	Standard	Delaware Bay to C&D Canal	3.5	5.1
Between DE Ports and Points **North**	Diverted	Delaware Bay to Ches. Bay; Ches. Bay to C&D Canal; Through C&D Canal	21.2	29.2
Between DE Ports and Points **South**	Standard	Ches. Bay to Delaware Bay; Delaware Bay to C&D Canal[2]	11.6	17.0
Between DE Ports and Points **South**	Diverted	Ches. Bay to C&D Canal; Through C&D Canal	13.1	17.3

Notes:

1. The legs traveled on a route may be in the order presented in each cell or in reverse order, depending on the route.
2. The legs traveled for this direction do not include the leg through the C&D Canal because this leg of a vessel's journey would not be affected by a spill in Delaware Bay.

For example, a voyage between Florida and New York, with stops in Baltimore and Wilmington, DE, would be broken into three "legs." The legs from Florida to Baltimore and from Baltimore to Wilmington, DE, would be unaffected by any oiling of the Delaware Bay entrance, since the vessel would arrive at Baltimore through the Chesapeake Bay and at Wilmington, DE, which is not projected to be oiled under any of the spill scenarios, through the C&D Canal. The third leg, however, would be diverted according to the "Between DE Ports and Points North" path, since it would have to backtrack through the C&D Canal and exit the Chesapeake Bay in order to reach New York. If the voyage did not include a stop in Baltimore, then the first leg from Florida to Wilmington, DE, would be diverted through the Chesapeake Bay and C&D Canal as well.

It is important to emphasize that the re-routing analysis is conducted for individual vessel trip legs as opposed to full vessel trips. This ensures that the analysis does not assign re-routing distances to vessels unaffected by a spill blocking Delaware Bay. For example, a vessel that is at the Port of Wilmington and bound for Baltimore via the C&D canal when a spill occurs would not be affected by a spill blocking the entrance to Delaware Bay. To analyze diversion at the level of the trip leg, this analysis relies on information in the USACE dataset indicating where a vessel is going and where it came from.

For vessels travelling to and from the north, the diversion results in an additional 24 Mt of fuel consumption, while those traveling to and from the south would only see an increase of about 0.3 Mt. However, because vessels travelling to and from the north constitute only 22 percent of included commercial traffic, the final weighted average additional fuel consumption per vessel is only 5.5 Mt.

Similarly, additional operating costs based on voyage time for vessels travelling between Delaware ports and points north amount to about $4,100, while those travelling between Delaware ports and points south amount to about $350. These values come from the previously calculated average daily operating costs for diverted vessels of $5,506 multiplied by the difference in voyage times between the original and diverted routes. The same weighted average formula incorporating the port direction (22 percent to/from the North) results in an additional operating cost of $1,154 per vessel.

The standard routes of all vessel legs in this analysis involve sailing through the Delaware Bay. According to communications with the Pilots Association for the Bay and River Delaware, a vast majority of vessels choose or are required to hire a Delaware pilot to guide the ship through the waters of the Delaware Bay and River. The Delaware pilotage costs are based on the ship dimensions and do not incorporate voyage duration. All diverted routes would eventually end up in the waters of the Delaware Bay, and would therefore be required to pay the same pilotage fees as if they had not diverted; therefore, the standard Delaware pilotage fees would ultimately cancel each other out.

The pilotage costs associated with vessel diversions are therefore exclusively the costs of traveling through the Chesapeake Bay and the C&D Canal. Both the Delaware and Maryland pilots' associations impose a flat C&D Canal usage fee totaling $2,266. Additionally, the Association of Maryland Pilots uses a rate structure incorporating both ship size and voyage duration, resulting in an average pilotage cost from the entrance of the Chesapeake Bay to the C&D Canal of $3,212. The additional pilotage costs associated with diverting from the Delaware Bay to the Chesapeake Bay and C&D Canal therefore total to approximately $5,478.

To find the total cost per vessel diverted, the weighted average additional fuel consumption per vessel of 5.5 Mt is multiplied by the previously described average price of VLSFO of $340.41/Mt, resulting in a total additional fuel cost of about $1,859 per vessel. Incorporating the average operating costs per diverted vessel ($1,154) and additional pilotage costs per vessel ($5,478) brings the total cost per diverted vessel to approximately $8,491.

RESULTS

For each modeled oil spill scenario, the total cost related to commercial shipping is the summation of costs to delayed vessels and diverted vessels. The costs to delayed vessels include the fuel and operating costs incurred while waiting until the entrance to the Delaware Bay is free of surface oiling. The costs to diverted vessels include the difference in fuel, operating, and pilotage costs between a vessel travelling the diverted route relative to the standard route.

Exhibits 5-9 and 5-10 list the lower and upper bound total cost estimates for each modeled oil spill scenario based on the blockage duration; number of vessels delayed and diverted; and cost of fuel consumption, operations, and pilotage previously described. Under the lower bound estimation of blockage days, costs range from $64,000 in the event of a medium-sized spill to $565,000 in the event of a well blowout scenario. Under the upper bound estimation, costs range from $307,000 in the event of a medium-sized spill to $902,000 in the event of a well blowout scenario. Across all spill scenarios, vessels delayed at sea face the highest costs as a proportion of total costs due to high fuel consumption costs. Among the costs associated with diversions, pilotage costs were higher than additional fuel consumption and operating costs combined. This is due to the relatively substantial pilotage costs associated with traversing the Chesapeake Bay and C&D Canal compared to the modest differences in fuel and operating costs between the standard and diverted routes.

Among the three states (i.e., Delaware, Virginia, and New Jersey), the number of spill scenarios resulting in the blockage of Delaware Bay is highest for the Delaware spill location, with 13 scenarios resulting in blockage. While the New Jersey and Virginia scenarios would result in fewer blockage instances (six and two, respectively), the duration of blockage associated with each spill size is assumed to be equal across all scenarios. The vessel data does not indicate substantial seasonal shifts in vessel entrances, so costs associated with commercial traffic delays and diversions are assumed to be constant across all seasons in the event of a blockage.

EXHIBIT 5-9. COMMERCIAL SHIPPING COSTS - LOWER BOUND (YEAR 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	$64,000	$64,000	$64,000	Not Blocked
	Surface	Unmitigated 200,000bbl	$207,000	$207,000	$207,000	Not Blocked
	Surface	Mitigated 200,000bbl	$126,000	$126,000	$126,000	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$565,000	$565,000	$565,000	$565,000
New Jersey	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	$64,000	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	$207,000
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$565,000	$565,000	$565,000	$565,000
Virginia	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	$207,000	Not Blocked	Not Blocked
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$565,000	Not Blocked	Not Blocked	Not Blocked

EXHIBIT 5-10. COMMERCIAL SHIPPING COSTS - UPPER BOUND (YEAR 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	$307,000	$307,000	$307,000	Not Blocked
	Surface	Unmitigated 200,000bbl	$566,000	$566,000	$566,000	Not Blocked
	Surface	Mitigated 200,000bbl	$426,000	$426,000	$426,000	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$902,000	$902,000	$902,000	$902,000
New Jersey	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	$307,000	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	$566,000
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$902,000	$902,000	$902,000	$902,000
Virginia	Surface	Unmitigated 126bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 2,240bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Surface	Unmitigated 200,000bbl	Not Blocked	$566,000	Not Blocked	Not Blocked
	Surface	Mitigated 200,000bbl	Not Blocked	Not Blocked	Not Blocked	Not Blocked
	Subsurface	Unmitigated 900,000bbl	$902,000	Not Blocked	Not Blocked	Not Blocked

For additional perspective on spill-related costs to commercial shipping, Exhibits 5-11 and 5-12 show the distribution of costs between diversion, delay at port, and delay at sea for each spill size category. The distributions shown in these exhibits apply to spills of a given size only for scenarios in which they are projected to result in a blockage of Delaware Bay. The exhibits also apply to all three spill locations. As Exhibits 5-11 and 5-12 show, delay costs far outweigh the costs associated with diversion, despite the fact that the number of vessels that would divert if blocked is less than the number that would delay (see Exhibit 5-7 above). This reflects the additional time and fuel consumption associated with delay. As indicated in Exhibit 5-8, the additional time associated with diversion is less than one day whereas the time associated with delay can be several days.

EXHIBIT 5-11. LOWER BOUND COSTS

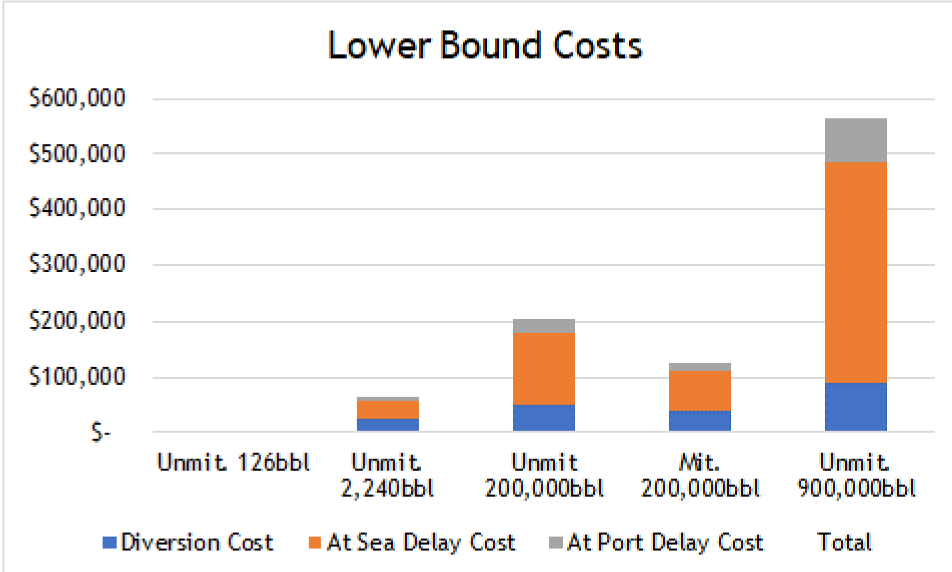
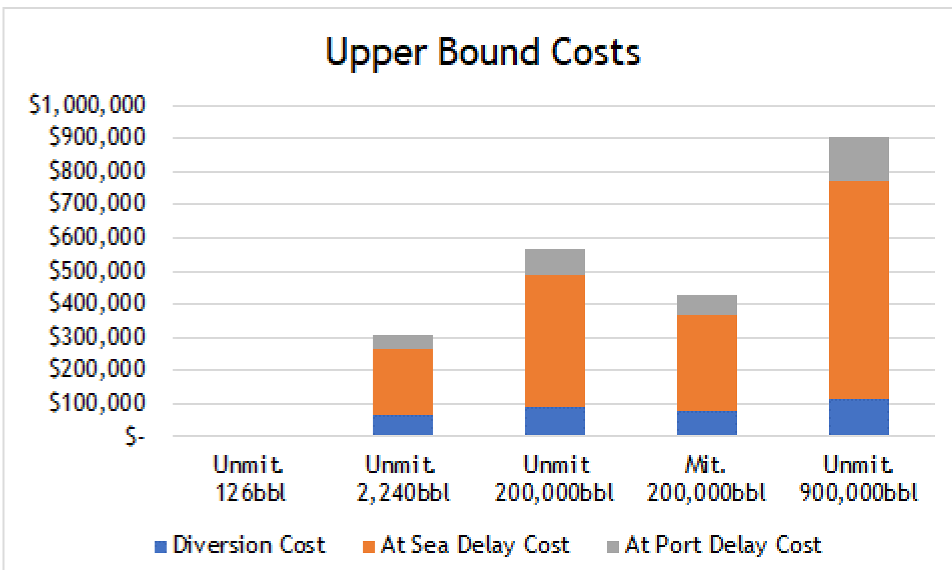


EXHIBIT 5-12. UPPER BOUND COSTS



KEY UNCERTAINTIES

Although this analysis provides reasonable estimates of the costs incurred by the shipping sector under each of the worst-case spill scenarios, the estimated costs are subject to a number of uncertainties. In particular, the overall analysis hinges on the assumption that vessels will choose to either delay their original route or follow the alternate route through the Chesapeake Bay and C&D Canal. However, due to the unpredictability of closure durations and lack of real-time information, some vessels capable of passing through the Canal may elect to stay in place and wait for the surface oiling to clear, even if route diversion would be faster. Likewise, time-sensitive cargo unable to access Delaware ports may be able to make spontaneous arrangements with alternate ports to unload their cargo.

The analysis also limits the scope of costs to include only the primary components of fuel consumption, operations, and pilotage. In practice, a spill may also lead to other costs such as tolls, vessel cleaning costs, and port fees. Additional costs could also stem from an increase in ship traffic congestion due to commercial vessel diversions through the Chesapeake Bay and oil spill response vessels throughout the region. The analysis also does not capture other welfare losses associated with the delayed shipment of goods. For example, Hummels and Schaur (2013) estimate willingness to pay for shorter transit time across approximately 1,000 product categories as an *ad valorem* premium (i.e., the percentage over the base price or value), suggesting that the welfare losses associated with delay may extend beyond the increases in shipping costs that result from delays.

CHAPTER 6 | RESPONSE COSTS

In the event of an offshore oil spill, response teams act quickly to minimize or prevent injury to natural resources. This chapter assesses the costs of spill response activities for each of the oil spill scenarios described in Chapter 2. Consistent with the analyses presented in prior chapters, the spills examined represent the worst-case scenarios for each spill volume, season, and location, measured by the total length of shoreline oiled. The total response costs include the removal of oil directly from the water, washed up on the shoreline, in ports, and in sensitive environments such as wetlands. Approaches to removal factored into the response cost calculations include dispersants, in-situ burning, and mechanical removal using tools such as skimmers and booms.

This analysis also allocates the calculated response cost to different types of payors based on historical trends. The Oil Pollution Act (OPA) of 1990 designates that the party found primarily responsible for an oil spill is liable for the costs of cleanup; however, in the event that the responsible party cannot be identified, the federal government covers response costs, drawing on resources from the Oil Spill Liability Trust Fund (OLSTF). Federal, state, local, and private entities engaged in cleanup operations are encouraged to submit reimbursement claims to the U.S. Coast Guard's National Pollution Funds Center, which adjudicates claims and, when appropriate and in accordance with OPA requirements, approves the disbursement of funds from the OLSTF.

To estimate response costs for each oil spill scenario, this analysis applies two approaches. Drawing on the published literature, the first approach involves the application of a series of multipliers to a predetermined base response cost per barrel corresponding to characteristics such as the type of shoreline oiled (e.g., sandy beach versus rocky surface). This approach is applied to the 126-barrel and 2,240-barrel spills. For the second approach, which is applied to larger spills (i.e., 200,000 barrels or more), this analysis draws on the experience of the *Exxon Valdez* and *Deepwater Horizon* spills.

APPROACH FOR 126-BARREL AND 2,240-BARREL SPILL SCENARIOS

To estimate response costs for the 126-barrel and 2,240-barrel spills, this analysis uses a response cost function derived in Etkin (2004) based on data for several thousand oil spills in U.S. waters over the period 1980 through 2002. Drawing on the response cost data and other information on these individual spills, Etkin (2004) specifies a response cost per gallon of oil spilled based on the following characteristics of the spill:

Oil Type Spilled: As presented in Etkin (2004), response costs vary across four different fuel types: light fuels, heavy oils, crude oil, and volatile distillates. For the purposes of this analysis, all modeled scenarios involve light fuels only, which Etkin (2004) defines as including light crude.

Spill Size: Etkin (2004) delineates six spill size categories to represent the higher per-unit cost of smaller spill volumes. The spill scenarios examined in this analysis involve four of the six spill size categories.

Primary Cleanup Method: Etkin (2004) accounts for three different primary cleanup methods: mechanical removal, dispersants, and in-situ burning.

Effectiveness of Cleanup: For each primary clean-up methods, Etkin (2004) specifies different levels of effectiveness. For mechanical removal, the effectiveness variants include 0 percent of oil removed, 10 percent removed, 20 percent removed, and 50 percent removed. For in-situ burns, the effectiveness values are 50 percent removal and 80 percent removal. For dispersants, effectiveness is simply specified as “low” or “high”. For the purposes of estimating response costs for unmitigated spills (such as the 126-barrel and 2,240-barrel scenarios examined in this analysis), the mechanical removal option with 0 percent removal efficiency is assumed to best represent response costs, given that this option results in the same degree of shoreline oiling as no mitigation at all. Exhibit 6-1 presents the response costs per barrel for each combination of spill size category, cleanup methods, and level of effectiveness.

Shoreline Type Oiled: Etkin (2004) also scales response costs based on the shoreline type(s) oiled. For each shoreline type, Etkin (2004) specifies a response cost multiplier, as shown in Exhibit 6-2. Due to the greater difficulty in cleaning oil from more sensitive environments such as wetlands and mudflats, the response cost multipliers are higher for these environments than, for example, for sandy or rocky environments.

EXHIBIT 6-1. BASE OIL SPILL RESPONSE COSTS PER BARREL FROM ETKIN (2004), BY SPILL SIZE, MITIGATION METHOD, AND REMOVAL EFFICIENCY (2019$)[1,2]

VOLUME (GALLONS)	MECHANICAL REMOVAL				DISPERSANT		IN-SITU BURN	
	0%	10%	20%	50%	LOW	HIGH	50%	80%
>500	$5,817	$4,945	$4,072	$3,316	$2,094	$1,454	$1,513	$756
500-1000	$5,701	$4,828	$3,956	$3,200	$2,036	$1,396	$1,454	$698
1000-10000	$5,643	$4,770	$3,898	$3,141	$1,978	$1,338	$1,396	$640
10000-100000	$5,061	$4,188	$3,432	$2,385	$1,513	$1,047	$1,047	$524
100000-1000000	$4,305	$3,607	$2,850	$1,513	$989	$582	$582	$291
>1000000	$1,803	$1,513	$989	$698	$640	$349	$407	$175

Notes:

1. Values from Table 1 of Etkin (2004) converted from $/gal to $/barrel and adjusted for inflation using the GDP deflator.
2. Values presented here represent the values for Light Fuels as reflected in Etkin (2004), which Etkin indicates includes light crude.

EXHIBIT 6-2. SHORELINE TYPE RESPONSE COST MULTIPLIERS

SHORELINE TYPE	MULTIPLIER
Rocky Shore/Artificial/ Manmade Shoreline	0.5
Sand/Gravel Beach	0.6
Mudflat	1.4
Wetland	1.6

To apply the shoreline type multipliers, this analysis calculated a weighted average multiplier to apply to the base unit cost for each spill scenario, based on the length of shoreline oiled, by shoreline type, as projected by the oil spill modeling described in Chapter 2. For instance, a scenario with a base cost of $2,000 per barrel (hypothetical value for illustration purposes) that oiled 10 miles of sandy beach (multiplier: 0.6) and 10 miles of wetland (multiplier: 1.6) would result in an adjusted cost of $2,200 per barrel, with 50 percent of the base cost being multiplied by the sandy beach multiplier ($1,000 × 0.6 = $600) and 50 percent by the wetland multiplier ($1,000 × 1.6 = $1,600).

APPROACH FOR 200,000-BARREL AND 900,000-BARREL SPILL SCENARIOS

To estimate the response costs for the much larger spill scenarios (i.e., 200,000 barrels and 900,000 barrels), this analysis draws on the response cost experience associated with the *Exxon Valdez* and *Deepwater Horizon* spills. Although the approach based on Etkin (2004) could be applied to these spills, the average spill response costs presented in Etkin (2004) largely reflect much smaller spills. As shown in Exhibit 6-2, the largest spill size category in Etkin (2004) is ">1,000,000 gallons", which corresponds to a cutoff of approximately 23,800 barrels. The large spills examined in this analysis exceed this threshold by a factor of 8 (for the 200,000-barrel spills) or factor of 37 (for the 900,000 spills).

The *Exxon Valdez* incident resulted in the spillage of 257,000 barrels of oil into Prince William Sound (Alaska Department of Fish and Game, Exxon Valdez Oil Spill Trustee Council). Exxon spent approximately $3.9 billion dollars (year 2019$) to contain and clean up the spill, or roughly $15,000 per barrel of oil spilled. The *Deepwater Horizon* incident resulted in the leakage of 3.19 million barrels into the GOM (U.S. District Court 2015).[33] BP spent approximately $16.8 billion on cleanup and containment, or roughly $5,300 per barrel of oil spilled (BP 2015).

For the 200,000-barrel and 900,000-barrel spill scenarios, this analysis uses the $5,300/barrel and $15,000/barrel values as starting points for estimating response costs. Because these values reflect the implementation of mitigation measures to limit the spread of oil, this analysis applies these values as low-end and high-end estimates of the response costs per barrel spilled for the mitigated 200,000-barrel spill. To derive estimates of per-barrel response costs that reflect no mitigation, this analysis adjusts the

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33 The Deepwater Horizon incident resulted in the release of approximately 4 million barrels, of which 800,000 barrels were recovered. Thus, 3.19 million barrels of oil were released into the Gulf of Mexico and not recovered. To minimize the potential for underestimating response costs per barrel, we calculate per-barrel costs using the 3.19 million barrel estimate.

$5,300/barrel and $15,000/barrel figures. The estimate of $15,000/barrel for the *Exxon Valdez* spill reflects the approximately 17,800 barrels of oil recovered through mechanical removal, which represents a removal efficiency of less than 10 percent. Based on the data presented in Exhibit 6-1 for spills greater than 1 million gallons, Etkin (2004) estimates that per-barrel response costs with mechanical recovery at an efficiency of 0 percent (no recovery) are approximately 19 percent higher, on average, than response costs with mechanical removal at 10 percent efficiency. Assuming that this differential applies to very large spills (200,000 to 900,000 barrels) and that 0 percent recovery is a reasonable representation of an unmitigated spill, this analysis applies a high-end response cost per barrel of $17,800/barrel to the unmitigated 200,000-barrel and 900,000-barrel spills.

As a low-end response cost per barrel for the unmitigated large spills, this analysis develops a similar adjustment for the $5,300/barrel response cost associated with the *Deepwater Horizon* spill. Of the approximately 4 million barrels spilled during that incident, 800,000 barrels were recovered, which translates to 20 percent efficiency. As shown in Exhibit 6-1 above, Etkin (2004) estimates that response costs with mechanical recovery at an efficiency of 0 percent (no recovery) are approximately 80 percent higher than response costs with 20 percent recovery. Applying this differential to the *Deepwater Horizon* response cost, this analysis assumes a low-end response cost per barrel of approximately $9,700 per barrel for the 200,000-barrel and 900,000-barrel spills.

ASSIGNMENT OF RESPONSE COSTS TO DELAWARE

The methods outlined in the previous sections provide estimates of the total response costs associated with a spill. These estimates therefore may reflect surface water and shoreline oiling in Delaware as well as surrounding states. In addition, the response cost estimates developed from the methods above do not distinguish between response costs incurred by individual states, the federal government, or the party responsible for a spill. This analysis therefore must isolate (1) the portion of response costs associated with oiling of Delaware coastline and Delaware waters and (2) the portion of these costs borne by the State of Delaware rather than the federal government or responsible party.

RESPONSE COSTS RELATED TO DELAWARE OILING

To isolate response costs specific to Delaware, this analysis assumed that the Delaware portion of response costs for a given spill was proportional to the fraction of surface oiling (above the 0.1 g/m^2 threshold specified in Chapter 2) within the Delaware coastal zone relative to the surface oiling along all coastal states in the region. This approach assumes that the response costs for each state directly relate to the amount of coastal zone oiling in that state. For example, 34 percent of the coastal surface oiling for the 2,240-barrel summer spill is off the coast of Delaware; this analysis therefore assigns 34 percent of response costs to Delaware for this scenario. Exhibit 6-3 shows the fraction of oiling within the Delaware coastal zone for each combination of spill location, season, and spill size category. As indicated in the exhibit, the percentage of oiling in Delaware's coastal zone is highest for the Delaware spills, due to the close proximity of these spills to the Delaware shoreline. For most of the spills off the coasts of New Jersey and Virginia, Delaware's coastal zone is projected to experience no oiling above the 0.1 g/m^2 threshold.

EXHIBIT 6-3. FRACTION OF SURFACE OILING IN DELAWARE STATE WATERS

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	0%	0%	0%	0%
	Surface	Unmitigated 2,240bbl	24%	34%	27%	0%
	Surface	Unmitigated 200,000bbl	27%	32%	11%	0%
	Surface	Mitigated 200,000bbl	45%	29%	25%	0%
	Subsurface	Unmitigated 900,000bbl	19%	19%	19%	34%
New Jersey	Surface	Unmitigated 126bbl	0%	0%	0%	0%
	Surface	Unmitigated 2,240bbl	0%	19%	0%	0%
	Surface	Unmitigated 200,000bbl	0%	0%	0%	1%
	Surface	Mitigated 200,000bbl	0%	0%	0%	0%
	Subsurface	Unmitigated 900,000bbl	22%	10%	32%	36%
Virginia	Surface	Unmitigated 126bbl	0%	0%	0%	0%
	Surface	Unmitigated 2,240bbl	0%	0%	0%	0%
	Surface	Unmitigated 200,000bbl	0%	2%	0%	0%
	Surface	Mitigated 200,000bbl	0%	0%	0%	0%
	Subsurface	Unmitigated 900,000bbl	5%	0%	0%	0%

RESPONSE COSTS INCURRED BY THE STATE OF DELAWARE

The Oil Pollution Act of 1990, crafted in the wake of the *Exxon Valdez* oil spill, standardizes the role of the responsible party as liable for covering response costs. In the event that the responsible party cannot be identified or cannot afford the costs, the Oil Spill Liability Trust Fund (OSLTF) is responsible for covering response costs. The OSLTF is funded primarily through a per-barrel excise tax on the petroleum industry, and supports EPA and Coast Guard cleanup efforts, natural resource damage assessments and restorations, research and development, and claims for uncompensated removal costs and damages from other federal, state, tribal, and private entities.

To estimate the portion of response costs related to Delaware oiling borne by the State of Delaware itself, this analysis relies on historical data on the distribution of response costs. Helton and Penn (1999) investigate how the response cost burden has typically been allocated between the responsible party and the public via the OSLTF. For spills with complete cost data, Helton and Penn (1999) estimate that the responsible party covers approximately 74 percent of response costs on average. The study categorizes the remaining 26 percent as "public," which broadly includes any other party involved in the cleanup process via the OSLTF.

The OSLTF Annual Reports indicate how the Fund is allocated to its three main expense categories: federal removal efforts by the U.S. EPA and U.S. Coast Guard, claims from other entities, and miscellaneous appropriations to assorted agencies and programs for research and development, enforcement, etc. The 2004-2008 report is the latest version to contain enough detailed cost data to inform this analysis. These reports show the Fund's compensation to Federal agencies for removal costs and payments to states and third parties for removal costs. While the latter includes payments to several different entities other than states and are used for natural resource damages, property damages, and lost profits in addition to removal costs, the report notes that the claims are primarily paid to states for removal costs. Using these data for the 2004 to 2008 period, the total state and third-party claims constitute approximately 40 percent of all response costs covered by the OSLTF, with claims from federal agencies representing the other 60 percent. Applying this split to the Helton and Penn (1999) finding that 26 percent of response costs are borne by public entities, this corresponds to roughly 10.4 percent of the total response cost paid by state governments, with 15.6 percent covered by the federal government. This analysis therefore assumes that 10.4 percent of response costs related to Delaware oiling are borne by the State of Delaware.

RESULTS

Applying the methods described above, Exhibits 6-4 and 6-5 present the estimated cost of spill response activities on or along Delaware's coast for each spill, with the former presenting low-end estimates and the latter presenting high-end estimates. These values include costs borne by the State of Delaware as well as costs borne by other parties (e.g., the federal government and responsible parties). Based on the assumption above that state governments incur 10.4 percent of response costs, Exhibits 6-6 and 6-7 present the portion of response costs likely to be borne by the State of Delaware. The red bars in all four exhibits show the relative magnitude of response costs across spill scenarios (i.e., the red bar for the highest-impact scenario fills an entire cell in each exhibit, and red bars for other cells are proportionately smaller based on the estimated response costs).

As all four exhibits indicate, response costs for oiling in the Delaware coastal zone are highest under the largest spill scenarios. Response costs are particularly high for the 900,000-barrel blowout scenarios, even though the modeled location for these scenarios is considerably farther from shore than the surface spill scenarios. At the other end of the spectrum, response costs for oiling in the Delaware coastal zone are estimated as $0 for each of the 126-barrel spill scenarios. In actuality, individual spills of approximately 126 barrels could result in response costs related to oiling in Delaware's coastal zone, but the oil spill modeling described in Chapter 2 suggests that 126-barrel spills in the specific locations chosen for this analysis would likely results in little to no response for oiling along Delaware's shoreline.

In addition to the 126-barrel spills, the results in Exhibits 6-4 to 6-7 show that response costs associated with oiling in Delaware's coastal zone are projected as $0 for most of the 126-barrel, 2,240-barrel, and 200,000-barrel scenarios off the coasts of New Jersey and Virginia. Although most of these spills will result in response costs, the oil spill modeling described in Chapter 2 suggests that there would be no surface oiling above the 0.1 g/m^2 threshold in the Delaware coastal zone under most of these scenarios. Exceptions include the unmitigated 200,000-barrel summer spill off the coast of Virginia, the unmitigated 200,000-barrel winter spill off the coast of New Jersey, and the 2,240-barrel summer spill off the coast of New Jersey. The response costs estimated for the last of these spills (the 2,240-barrel spill off the coast of New Jersey) stands in contrast to the $0 in response costs projected for the larger 200,000-barrel summer spill off New Jersey. Consistent with similar findings presented in earlier chapters of this report, this result reflects how the worst-case spill is defined for each scenario. As described in Chapter 2, the specification for the worst-case scenario is based on the maximum shoreline oiled across the entire Mid-Atlantic region rather than the maximum shoreline oiling on Delaware's coast. In the case of the 200,000-barrel summer spill off the coast of New Jersey, the maximum shoreline oiling is projected when currents and winds carry the oil northward, causing significant oiling along the coast of New Jersey and the southern coast of Long Island, but no oiling to Delaware's coast and no surface oiling above the critical threshold in Delaware's coastal zone. As a sensitivity analysis, the appendix to this report presents response cost estimates under an alternative specification of the 200,000-barrel summer spills off the coast of New Jersey, using the same conditions as assumed for the 126- and 2,240-barrel worst-case spills.

EXHIBIT 6-4. COSTS RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS - LOW END ESTIMATES (2019$)

LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$2,020,000	$2,810,000	$2,290,000	$0
	Surface	Unmitigated 200,000bbl	$513,820,000	$609,120,000	$214,720,000	$0
	Surface	Mitigated 200,000bbl	$481,680,000	$304,750,000	$261,170,000	$0
	Subsurface	Unmitigated 900,000bbl	$1,681,210,000	$1,615,140,000	$1,645,350,000	$2,984,130,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$1,630,000	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0	$12,270,000
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$1,933,160,000	$837,510,000	$2,819,620,000	$3,165,360,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$34,870,000	$0	$0
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$439,650,000	$0	$0	$0

EXHIBIT 6-5. COSTS RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS - HIGH END ESTIMATES (2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$2,020,000	$2,810,000	$2,290,000	$0
	Surface	Unmitigated 200,000bbl	$948,240,000	$1,124,100,000	$396,260,000	$0
	Surface	Mitigated 200,000bbl	$1,363,240,000	$862,510,000	$739,170,000	$0
	Subsurface	Unmitigated 900,000bbl	$3,102,590,000	$2,980,660,000	$3,036,410,000	$5,507,080,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$1,630,000	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0	$22,650,000
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$3,567,560,000	$1,545,590,000	$5,203,480,000	$5,841,520,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$64,340,000	$0	$0
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$811,360,000	$0	$0	$0

EXHIBIT 6-6. COSTS BORNE BY THE STATE OF DELAWARE RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS - LOW END ESTIMATES (2019$)

LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$210,000	$290,000	$240,000	$0
	Surface	Unmitigated 200,000bbl	$53,580,000	$63,510,000	$22,390,000	$0
	Surface	Mitigated 200,000bbl	$50,220,000	$31,780,000	$27,230,000	$0
	Subsurface	Unmitigated 900,000bbl	$175,300,000	$168,410,000	$171,560,000	$311,150,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$170,000	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0	$1,280,000
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$201,570,000	$87,330,000	$293,990,000	$330,040,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$3,640,000	$0	$0
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$45,840,000	$0	$0	$0

EXHIBIT 6-7. COSTS BORNE BY THE STATE OF DELAWARE RELATED TO OIL SPILL RESPONSE ALONG DELAWARE'S COAST OR IN DELAWARE WATERS - HIGH END ESTIMATES (2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$210,000	$290,000	$240,000	$0
	Surface	Unmitigated 200,000bbl	$98,870,000	$117,210,000	$41,320,000	$0
	Surface	Mitigated 200,000bbl	$142,140,000	$89,930,000	$77,070,000	$0
	Subsurface	Unmitigated 900,000bbl	$323,500,000	$310,790,000	$316,600,000	$574,210,000
New Jersey	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$170,000	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0	$2,360,000
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$371,980,000	$161,150,000	$542,550,000	$609,080,000
Virginia	Surface	Unmitigated 126bbl	$0	$0	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$6,710,000	$0	$0
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$84,600,000	$0	$0	$0

KEY UNCERTAINTIES

The analysis presented in this chapter provides an informed assessment of the response costs likely to be incurred by the State of Delaware as a result of oil spills of varying sizes occurring off the coasts of Delaware, Virginia, and New Jersey. This analysis, however, is subject to a number of uncertainties, the most significant of which are as follows:

- The response cost estimates are based on average response costs per barrel derived from data from several historical spills. Ideally, the analysis would draw on a dataset of Delaware-specific spills to ensure that it accurately reflects the characteristics of response activities in Delaware. Such Delaware-specific spill response data, however, are limited and do not capture the full range of spills included in this analysis.
- The approach for spatially allocating response costs to Delaware (as opposed to neighboring states) makes the simplifying assumption that the distribution of response costs is proportional to the degree of oiling in the waters along each state's coast. In an actual spill situation, the distribution of costs across affected states may reflect a number of factors that this analysis was unable to account for, such as the characteristics of the coastline in individual states and the roughness of the surf along different states' shorelines.
- The Etkin (2004) approach does not include a true representation of response costs without mitigation. As described above, this analysis applies the Etkin (2004) unit response cost with mechanical removal at 0 percent efficiency to represent response costs without mitigation. Because this estimate includes the costs of mechanical removal, it may overestimate unmitigated response costs. Similarly, the response costs for the *Exxon Valdez* and *Deepwater Horizon* spills that serve as the basis for estimating response costs associated with the 200,000-barrel and 900,000-barrel spills are not a true representation of response costs without mitigation. To apply the response costs per barrel from the *Exxon Valdez* and *Deepwater Horizon* spills to unmitigated spills, we make the simplifying assumption that the proportional differential between mitigated and unmitigated response costs, as derived from Etkin (2004), would apply to these larger spills.
- The application of Etkin (2004) required calculation of response costs for an entire spill event, followed by spatial distribution of response costs to geographic areas. One limitation of this approach is that the total response cost estimates derived from Etkin (2004) reflect the distribution of affected shoreline types across the entire area affected, not just the Delaware coast. Therefore, to the extent that the distribution of shoreline types in Delaware is systematically different than the distribution for the broader region, this analysis may overestimate or underestimate spill response costs to Delaware.

For each oil spill scenario, the previous chapters quantify and monetize changes in activity along Delaware's coast that are reliant on coastal and marine resources. To monetize these effects, this analysis applies varying measures of impacts, including changes in consumer welfare (for recreation in Chapter 3), changes in landings revenue (for commercial fishing in Chapter 4), and increases in costs borne by the private or public sector (for commercial shipping and response costs in Chapters 5 and 6, respectively). Policymakers and the public, however, may also be interested in understanding how spill-related changes in activity may affect the Delaware economy and the State's finances. The purpose of this chapter is to assess these economic and fiscal impacts, measured in terms of employment, state level gross domestic product (GDP), labor income, and revenues collected by the State.

The scope of the analysis presented in this chapter includes economic and fiscal impacts associated with spill-related changes in recreational and commercial fishing activity. Although changes in commercial shipping activity and spill response may have implications for the Delaware economy, the magnitude of these effects is highly uncertain. In the case of commercial shipping, any reductions in economic activity associated with a spill would likely arise from reduced traffic at Delaware ports, either from a temporary port closure or vessels re-routing to other ports as a result of a spill. The shipping effects described in Chapter 5, however, would not necessarily lead to port closures or reduced activity at Delaware ports. Instead, they may simply delay the arrival of affected vessels by a few days (and delay departures for some vessels at port), reducing activity on some days and increasing it on others. With respect to spill response, although the use of State resources on response activity would divert resources from other uses that benefit the Delaware economy, the temporary influx of spill response workers on behalf of the responsible party or the federal government would at least partially offset these effects. Due to these factors, impacts to the Delaware economy related to commercial shipping and spill response are excluded from the analysis presented in this chapter.

APPROACH

To assess the economic and fiscal impacts associated with each oil spill scenario, this analysis applies the IMPLAN input-output model. Input-output models are a well-established framework for assessing the economic and fiscal impacts associated with a change in expenditures for one or several industries across multiple sectors of the economy. Using detailed data on inter-industry relationships, input-output models estimate how a positive or negative shock in one industry (e.g., a change in output) cascades across the broader economy. Thus, in addition to capturing direct economic impacts for industries with reduced (or increased) production, input-output models capture spillover effects to other industries. These spillover effects include indirect impacts and induced impacts. Indirect impacts reflect inter-industry purchases and arise from firms purchasing inputs from their suppliers. For example, in the context of expenditures on meals at restaurants, indirect impacts would include the employment associated with producing the meat and poultry used as ingredients in restaurant meals. Induced impacts, by contrast, result from wages paid to workers, who may spend these wages on consumer electronics, clothing, etc. Again, in the context of expenditures on restaurant meals, induced effects include the economic impacts associated with servers, cooks, and other restaurant workers spending their earnings.

Like most input-output models, IMPLAN estimates economic impacts in terms of changes in employment, labor income, value added,[34] and output, and distinguishes between direct, indirect, and induced effects. The model also estimates changes in tax revenues collected by various levels of government (e.g., federal and state). IMPLAN reports its results at the 3- to 4-digit NAICS level for the agricultural and service sectors, and at the 4- to 5-digit NAICS level for manufacturing industries. In the current version of IMPLAN with year 2019 data, this amounts to 546 industry sectors. The geographic scope of IMPLAN may be modified to accommodate the needs of a specific analysis. Model runs can be conducted nationally, for regional groupings of states, individual states, groups of counties within states, or for individual counties. The IMPLAN analysis presented in this chapter is for the state of Delaware as a whole. The input-output data within IMPLAN are derived from County Business Pattern data published by the U.S. Census Bureau, the U.S. Bureau of Economic Analysis' (BEA's) Regional Economic Accounts, and the Bureau of Labor Statistics' Census of Employment and Wages.

The use of IMPLAN for this analysis involved (1) the development of inputs for use in IMPLAN, (2) the running of IMPLAN, and (3) the post-processing of IMPLAN results. Each of these steps is described in detail below.

DEVELOPMENT OF IMPLAN INPUTS

The inputs developed for the IMPLAN runs reflect spill-specific changes in economic activity associated with reductions in coastal/marine recreation and commercial fishing. For recreation, these inputs include various expenditure reductions related to the decline in beach use, recreational fishing, and recreational boating following a spill. These include reduced expenditures on lodging, restaurant meals, groceries, bait and tackle, entertainment, and related items. For commercial fishing, the reduction in commercial fishery output itself may be used as an input in IMPLAN. In addition, because there are various activities in the seafood supply chain that are downstream from commercial fishing, such as seafood processing and wholesaling, the IMPLAN inputs for this analysis include activity changes for these downstream activities as well.

[34] Value added is the degree to which the value of a good is increased at each link in the supply chain, exclusive of initial costs. For example, value added for the restaurant industry includes the value associated with preparing meals from purchased ingredients and serving those meals to customers. The cost of the food ingredients obtained from suppliers, however, is not included in the restaurant industry's value added.

IMPLAN Inputs Related to Reduced Recreational Activity

To develop IMPLAN inputs associated with reductions in recreational activity, this analysis draws on published studies characterizing the amount and composition of expenditures per individual beach day, recreational fishing trip, and recreational boating trip. For expenditures related to beach use, this study relies on the findings of NOAA's 2012 National Ocean Recreation Expenditure Survey (Kosaka and Steinback 2018). NOAA conducted the survey to collect data on annual participation (number of people), effort levels (number of user days), and annual spending associated with a wide range of ocean and coastal activities by region. The expenditure data collected as part of the survey include not only the total level of expenditures per recreation day, but also the distribution of expenditures across different goods and services. To capture expenditures unique to beach recreation, this analysis combines the reported expenditure data for the Mid-Atlantic for three categories of recreation: (1) viewing or photographing the ocean; (2) beachcombing, tide pooling, or collecting items; and (3) outdoor activities not involving water contact (e.g., sunbathing).[35]

Exhibit 7-1 shows the estimated expenditures per beach user day derived from these data and the composition of these expenditures. The left-hand column in the exhibit identifies the individual spending categories as they are presented in Kosaka and Steinbeck (2018). The expenditure categories shown in the exhibit include those expenditure types most likely to be affected by the number of beach trips taken in a given year. These include expenditures on consumables as well as semi-durable goods that individuals often purchase while at the beach or while preparing for a beach trip (e.g., clothing). Expenditures on highly durable goods (e.g., boats) or seasonal/annual fees (e.g., for club dues) are excluded, as these are less likely to be affected by an individual's cancellation of a beach trip. The expenditures shown in Exhibit 7-1 represent the average per user day across *all* users. For example, the average of $28.60 per user day for "Lodging – hotel, campground" reflects expenditures for individuals who stayed overnight and required lodging and individuals who took day trips and did not require lodging. As Exhibit 7-1 shows, the expenditures associated with a day of beach recreation are dominated by expenditures on lodging, food, and fuel.

To apply these expenditure-per-trip values in IMPLAN, each expenditure category must be mapped with a specific commodity or industry. The right most column in Exhibit 7-1 shows the IMPLAN commodity(s) or industry(s) mapped to each expenditure category. For groceries, expenditures are mapped according to the distribution for food and beverages purchased for off-premises consumption, as reported in Table 2.4.5 of the Bureau of Economic Analysis' National Income and Product Accounts.[36] When modeling the impact of expenditure changes for each commodity/industry shown in Exhibit 7-1, IMPLAN accounts for whether it was produced in Delaware when estimating employment, labor income, and other economic impacts specific to Delaware.

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[35] The Mid-Atlantic is defined to include the following states for the purposes of the NOAA survey: New York, New Jersey, Pennsylvania, Maryland, Delaware, West Virginia, and Virginia.

[36] See Burau of Economic Analysis, National Income and Product Accounts, Table 2.4.5 - Personal Consumption Expenditures by Type of Product, release of March 25, 2021.

EXHIBIT 7-1. ESTIMATED EXPENDITURES PER BEACH DAY

CATEGORY	SPENDING PER USER DAY (2019$)	IMPLAN COMMODITY/INDUSTRY
Auto fuel	$20.27	Commodity 3154: Refined Petroleum Products
Auto rental	$0.46	Industry 450: Automotive equipment rental and leasing
Bus, taxi, etc.	$1.35	Commodity 3418: Transit and ground passenger transportation services
Parking and site access	$2.23	Industry 501: Museums historical sites, zoos, and parks.
Lodging - hotel, campground	$28.60	Commodity 3507: Hotels and motel services, including casino hotels Commodity 3508: Other accommodation services
Lodging - all inclusive resort	$0.11	Commodity 3507: Hotels and motel services, including casino hotels Commodity 3508: Other accommodation services
Food - restaurants, bars, etc.	$34.27	Commodity 3509: Full-service restaurant services Commodity 3510: Limited-service restaurant services Commodity 3511: All other food and drinking place services
Food - grocery, convenience stores	$9.60	Various Commodities
Equipment for beachcombing (e.g., metal detector, buckets)	$0.41	Commodity 3234: Hand tools Commodity 3339: All other miscellaneous electrical equipment & components
Equipment, gear for biking, hiking, etc.	$0.03	Commodity 3362: Motorcycles, bicycles, and parts Commodity 3130: Footwear
Binoculars, etc.	$2.31	Commodity 3270: Optical instruments and lenses
Cameras, etc.	$3.50	Commodity 3271: Photographic and photocopying equipment
Horseback riding	$0.18	Industry 498: Racing and Track Operation Industry 504: Other amusement and recreation industries
Horse maintenance	$0.12	Commodity 3131: Other leather and allied products Commodity 3382: Sporting and athletic goods
Field guides, etc.	$0.05	Commodity 3426: Directories, mailing lists, and other published materials
Clothing, etc.	$4.68	Commodity 3125: Men's and boys' cut and sew apparel Commodity 3126: Women's and girls' cut and sew apparel Commodity 3127: Other cut and sew apparel
Camping equipment	$0.69	Commodity 3382: Sporting and athletic goods
Volleyball, frisbee, etc.	$0.10	Commodity 3382: Sporting and athletic goods
Biking, etc.	$0.07	Commodity 3362: Motorcycles, bicycles, and parts
Walking, running, etc.	$0.15	Commodity 3130: Footwear
Sunbathing, etc.	$0.55	Commodity 3118: Curtains and Linens Commodity 3171: Medicines and botanicals
TOTAL	**$109.74**	

Source: Derived from Kosaka and Steinback (2018).

For recreational fishing, this analysis adapts expenditure data from NOAA's *The Economic Contribution of Marine Angler Expenditures in the United States* (Lovell et al. 2013). Based on NOAA's National Marine Recreational Fishing Expenditure Survey, this report includes state-level data on expenditures by recreational anglers, both in aggregate and at the trip level. This analysis applies the Delaware-specific data included in the study. Similar to the expenditure data described above for beach recreation, the data on recreational fishing expenditures reflect expenditures on both consumable goods and durable goods.[37] For the purposes of this analysis, only those categories likely to change as a result of a temporary reduction in activity were included. This analysis therefore excludes expenditure categories from the NOAA report associated with highly durable goods (e.g., boats and new vehicle purchases). Exhibit 7-2 presents the categories of expenditures included and the level of per-trip expenditures associated with each category. The exhibit also shows the IMPLAN commodities and industries mapped to each expenditure category. Similar to expenditures for beach recreation, expenditures on groceries were mapped to various IMPLAN commodities based on the distribution for food and beverages purchased for off-premises consumption, as reported by the Bureau of Economic Analysis.

To characterize expenditures related to recreational boating, this analysis draws on data collected through the Mid-Atlantic Recreational Boater Survey developed by the Monmouth University Urban Coast Institute (2016). Conducted from May through October 2013, the survey asked boat owners about expenditures on their most recent trip. Among surveyed boat owners, 715 respondents were deemed eligible and completed the survey. The survey results, adjusted to year 2019 dollars, are presented in Exhibit 7-3, along with the IMPLAN commodities/industries mapped to each expenditure type. As suggested by the exhibit, one adjustment was made to the survey results to make them applicable to this study. Because the analysis of boating activity presented in Chapter 3 focuses on the number of boating trips taken by all individuals rather than just boat owners, the expenditures per boat owner were adjusted to represent the average expenditure per individual boater, based on the assumption of approximately 2.64 individuals per boat trip referenced in Chapter 3 (Lupi 2015). In making this adjustment, this analysis assumes that boat owners make most expenditures on behalf of the individuals joining them on the boat. That is, the expenditures reported by boat owners in response to the Mid-Atlantic Recreational Boater Survey are distributed across all individuals on the average boating trip. Though it is possible that some individuals joining a boat owner on his or her boat may purchase items on their own, boat owners who are boating with family or hosting friends for the trip are likely to purchase many of the items needed for the trip. Thus, to avoid the overestimation of expenditures, this analysis assumes that all purchases for a boat trip are made by boat owners.

[37] While the study reports expenditures on consumables on a per-trip level, expenditures on semi-durables and durables are reported on a per-angler basis. To generate per-trip expenditures for these items, the per-angler estimates were multiplied by the number of anglers, and then divided by the number of fishing trips among those surveyed.

EXHIBIT 7-2. ESTIMATED EXPENDITURES PER RECREATIONAL FISHING TRIP

CATEGORY	SPENDING PER TRIP (2019$)	IMPLAN COMMODITY/INDUSTRY
Auto Fuel	$16.72	Commodity 3154: Refined Petroleum Products
Bait	$8.24	Commodity 3382: Sporting and athletic goods
Food from Grocery Stores	$8.91	Various
Food from Restaurants	$6.10	Commodity 3509: Full-service restaurant services Commodity 3510: Limited-service restaurant services Commodity 3511: All other food and drinking place services
Gifts & Souvenirs	$0.62	Commodity 3411: Retail services - general merchandise stores
Ice	$1.28	Commodity 3105: Manufactured Ice
Lodging	$5.48	Commodity 3507: Hotels and motel services, including casino hotels Commodity 3508: Other accommodation services
Parking & Site Access	$0.46	Industry 501: Museums historical sites, zoos, and parks.
Tackle	$23.51	Commodity 3382: Sporting and athletic goods
Rods & Reels	$15.52	Commodity 3382: Sporting and athletic goods
Spearfishing Gear	$0.00	Commodity 3382: Sporting and athletic goods
Binoculars	$0.21	Commodity 3270: Optical instruments and lenses
Camping Equipment	$2.93	Commodity 3382: Sporting and athletic goods
Clothing	$3.32	Commodity 3125: Men's and boys' cut and sew apparel Commodity 3126: Women's and girls' cut and sew apparel Commodity 3127: Other cut and sew apparel
TOTAL	**$93.30**	

Source: Lovell et al. (2013).

EXHIBIT 7-3. ESTIMATED EXPENDITURES PER RECREATIONAL BOATING TRIP

CATEGORY	BOAT OWNER SPENDING PER TRIP (2019$)	SPENDING PER TRIP, PER BOATER (2019$)	IMPLAN COMMODITY/INDUSTRY
Equipment, maintenance, repairs and upkeep	$94.40	$35.76	Industry 361: Boat Building
Boat fuel and oil	$85.97	$32.56	Commodity 3154: Refined Petroleum Products
Restaurant meals & drinks	$54.71	$20.72	Commodity 3509: Full-service restaurant services Commodity 3510: Limited-service restaurant services Commodity 3511: All other food and drinking place services
Groceries	$25.99	$9.85	Various
Transient/guest dockage (marina fee)	$25.36	$9.61	Commodity 3416: Water Transportation Services
Auto gas and oil	$23.08	$8.74	Commodity 3154: Refined Petroleum Products
Fishing gear, bait, ice, etc.	$15.12	$5.73	Commodity 3382: Sporting and athletic goods
Recreation and entertainment	$8.79	$3.33	Commodity 3501: Museum, heritage, zoo and recreational services Commodity 3502: Amusement parks and arcades Commodity 3504: Other amusement and recreation
Lodging (hotel/motel)	$7.28	$2.76	Commodity 3507: Hotels and motel services, including casino hotels
Shopping and souvenirs	$4.12	$1.56	Commodity 3411: Retail services - general merchandise stores
Lodging (camping/B&B)	$2.88	$1.09	Commodity 3508: Other accommodation services
Launch fees	$2.15	$0.81	Commodity 3416: Water Transportation Services
Pump out fees	$0.46	$0.18	Commodity 3416: Water Transportation Services
TOTAL	**$350.32**	**$132.70**	

Source: Monmouth University Urban Coast Institute (2016).

Based on the expenditure profiles in Exhibits 7-1 through 7-3 and the spill-specific changes in beach use, recreational fishing, and recreational boating presented in Chapter 3, this analysis estimates the level and composition of recreation-related expenditure effects associated with each spill scenario.

IMPLAN Inputs Related to Reduced Commercial Fishing Activity

The IMPLAN inputs developed for the commercial fishing industry include measures of reduced activity within the commercial fishing industry itself as well as measures of reduced activity for downstream industries that rely on commercially caught fish as inputs. To assess impacts specific to the commercial fishing industry, this analysis uses the changes in landings revenue associated with a given spill scenario as the input to IMPLAN. These values are presented in Chapter 3. Within the IMPLAN framework, these values are entered as a change in output for the commercial fishing industry (IMPLAN sector 17).

This analysis also incorporates inputs into IMPLAN for four industries that are downstream from commercial fishing in the seafood value chain: (1) seafood processing, (2) restaurants, (3) wholesalers, and (4) retail markets. Effects related to these downstream industries are examined separately from impacts associated with commercial fishing itself because IMPLAN's assessment of indirect and induced effects captures upstream but not downstream impacts. Put differently, when modeling the impacts associated with a change in activity for a given industry, IMPLAN captures how this change affects the industry's suppliers but not its customers. The downstream activity for the four industries identified above are therefore not reflected in IMPLAN estimates of the indirect effects associated with reduced commercial fishery landings.

As an initial step in developing inputs related to the downstream sectors identified above, this analysis allocates commercial landings to these sectors, based on a distribution developed by the NOAA National Marine Fisheries Service (2011), as shown in Exhibit 7-4. As indicated in the exhibit, approximately three-quarters of landed fish are sent to processors or wholesalers. The exhibit also indicates that 12.5 percent are exported or sold directly to final consumers. This analysis does not estimate downstream economic impacts for this portion of landings and instead focuses on the 87.5 percent of landings allocated to the other sectors listed in the exhibit.

EXHIBIT 7-4. ALLOCATION OF COMMERCIAL FISHERY LANDINGS TO DOWNSTREAM SECTORS

SECTOR	PERCENT ALLOCATION
Processors	30.0%
Wholesalers/Distributors	45.0%
Restaurants/food service	2.5%
Groceries/retail markets	10.0%
Exports	7.0%
Final Consumers	5.5%
TOTAL	100.0%

Source: NOAA National Marine Fisheries Service (2011).

To develop IMPLAN inputs for downstream sectors, this analysis relied on one approach for local (within Delaware) processors and restaurants and another for local wholesalers and retailers. For processors and restaurants, the IMPLAN input used in this analysis is the change in sales, or gross output as termed in IMPLAN, for these industries as a result of the spill-related change in commercially caught fish available to them as inputs (e.g., the sales revenues for seafood meals that restaurants are unable to produce and sell due to the reduction in seafood available to them). The changes in gross output for the seafood processing and restaurant industries were estimated by applying the ratio of gross output to food input for each industry, as derived from IMPLAN data, to the value of commercial fishery landings allocated to each downstream sector. The following equation summarizes this approach:

$$g_{i,s} = a_i \times l_s \times \frac{G_i}{F_i}$$

Where $g_{i,s}$ = change in gross output for downstream industry i (seafood processing or restaurant industries) under oil spill scenario s;

a_i = fraction of commercial fishing landings allocated to downstream industry i, based on the distribution in Exhibit 7-4;

l_s = the reduction in commercial fishery landings under oil spill scenario s, as estimated in Chapter 3;

G_i = total gross output for industry i, as reported in IMPLAN, and

F_i = total value of food inputs used by industry i, as identified in IMPLAN.

In the above equation, the expression ($a_i \times l_s$) represents landings allocated to a given downstream sector. The output that each downstream sector produces based on these landings is calculated by scaling that value by the ratio G_i/F_i. For the seafood processing industry, the ratio G_i/F_i is 1.89. For the restaurant industry, the value of this ratio is 11.91. Note that the denominator of this ratio is total *food* inputs rather than total seafood input. This is due to the fact that not all output produced by the restaurant industry is necessarily seafood products. For example, restaurants sell drinks, salads, desserts, etc. While most sales from the seafood processing industry are likely seafood products, the choice of using food inputs rather than seafood inputs for this industry has minimal impact on the results of the analysis, as seafood accounts for more than 80 percent of the industry's food inputs, based on the IMPLAN data. Thus, using the ratio of total output to food inputs for the seafood processing industry results in a slightly conservative estimate of economic impacts.

Based on this approach, this analysis estimates that every $1,000 in reduced commercial fishery landings results in reduced output of approximately $568 for the seafood processing industry and $298 for the restaurant industry. These values serve as the basis for generating the IMPLAN inputs used to estimate downstream economic impacts associated with seafood processors and restaurants. For every $1,000 in reduced landings, this analysis estimates the impact associated with a $568 reduction in gross output for

Delaware's seafood processing industry (IMPLAN sector 92 – Seafood product preparation and packaging) and a $298 reduction in gross output for the state's restaurant industry (IMPLAN sector 509 – Full-service restaurants).

For the wholesale and retail industries, this analysis generates IMPLAN inputs based on information in IMPLAN on the fraction of total value added for seafood products contributed by the wholesale sector and retail sector relative to the commercial fishing and seafood processing industries. As shown in Exhibit 7-5, the wholesale and retail industries account for 5.4 percent and 27.2 percent of margin value, respectively, for seafood products, while the seafood industry itself (and its upstream suppliers) accounts for approximately 66.1 percent. Based on this information, IMPLAN inputs for the wholesale and retail industries were generated through a two-step process:

- ***Step 1: Calculate retail and wholesale margin value associated with a given change in commercial fishery landings:*** The relative relationships between the different values in Exhibit 7-5 allow for estimation of both wholesale and retail value added associated with a given change in landings revenue. The following equation illustrates this approach:

$$V_{wr} = a_i \times l_s \times \frac{M_{wr}}{M_f}$$

  Where V_{wr} = value added for the wholesale or retail sector associated with a given reduction in commercial fishery landings;

  a_i is as defined above;

  l_s is as defined above;

  M_{wr} = wholesale or retail fraction of final seafood product margin (as presented in Exhibit 7-5), and

  M_f = portion of final seafood product margin attributed to seafood product production and processing.

  Based on this equation, every $1,000 in reduced commercial fishery landings results in a $37 reduction in value added for wholesalers and a $41 reduction in value added for retailers.[38]

- ***Step 2: Calculate Employee Compensation Portion of Value Added Changes from Step 1:*** As inputs for assessing the economic impacts of a given scenario, IMPLAN can use exogenously specified changes in individual elements of value added but not total value added. These value added elements include employee compensation, proprietor income, other property income, and taxes on production. For the purposes of this analysis, employee compensation was used as the input to IMPLAN. Based on the industry-specific data in IMPLAN on the components of value added, employee compensation makes up 76 percent of value added for the "Wholesale – Grocery and related product wholesalers"

[38] For example, the $37 figure for wholesalers reflects $450 in landings diverted from wholesalers (45% of $1,000). Based on the data in Exhibit 7-5, this figure was scaled down by the ratio 5.4/66.1.

industry (IMPLAN sector 398) in Delaware and 72 percent of value added for Delaware's "Retail – Food and beverage stores" industry (IMPLAN sector 406). These values were applied to the values generated by Step 1 above to derive estimates of wholesale and retail employee compensation per $1000 of landings. The resulting values are $28 in wholesale industry employee compensation per $1000 in landings and approximately $30 in retail industry employee compensation per $1000 in landings. These values were applied to the reduction in Delaware seafood industry landings for each scenario to generate IMPLAN inputs for the wholesale and retail industries.

EXHIBIT 7-5. ALLOCATION OF SEAFOOD MARGIN TO INDIVIDUAL COMMODITIES

COMMODITY	FRACTION OF FINAL SEAFOOD PRODUCT VALUE ADDED
Seafood products	66.1%
Wholesale services	5.4%
Retail services	27.2%
Air transportation services	0.1%
Rail transportation services	0.07%
Water transportation services	0.002%
Truck transportation services	1.1%
TOTAL	100.0%
Source: IMPLAN	

PERFORM IMPLAN MODEL RUNS

Based on the inputs specified above, in terms of the overall dollar amounts and their distribution across different IMPLAN industries and commodities, IMPLAN model runs were performed to estimate the direct, indirect, and induced economic impacts associated with spill-related changes in recreation and commercial fishing activity. The geographic scope of the IMPLAN runs was limited to the State of Delaware.

POST-PROCESSING OF IMPLAN OUTPUTS

After performing the IMPLAN runs described above, the model outputs were processed and aggregated to generate estimates of the economic and fiscal impacts of each oil spill scenario. For the IMPLAN results related to commercial fishing, the processing of outputs was necessary to avoid the double counting of impacts. Specifically, the *indirect* impacts estimated by IMPLAN in the model runs focusing on the downstream seafood processing and restaurant industries include impacts to the commercial fishing industry. These impacts, however, are also reflected (as direct impacts) in the IMPLAN analyses of the commercial fishing industry itself. Summing the results for the seafood processing and restaurant industries with the results for the commercial fishing industry would therefore result in double counting. To avoid the double-counting of effects, this analysis excludes the indirect impacts associated with the commercial fishing industry from the model run results for the seafood processing and restaurant model runs. A similar adjustment is also made for induced effects (i.e., to exclude induced effects related to indirect changes in worker income within the commercial fishing industry).

The other post-processing adjustment relates to IMPLAN's estimates of state government revenue impacts. Changes in these revenues are included in IMPLAN's standard outputs and reflect revenues collected from, among other sources, sales taxes (including hospitality taxes for hotel stays), corporate profit taxes, personal income tax, various licensing fees, and motor vehicle excise taxes. In the context of an oil spill, however, not all of these revenue streams would necessarily change. For example, vehicle owners would still likely pay the excise taxes on their cars and trucks, and businesses—even if they experience a downturn in revenues—would still likely pay their licensing fees to the state so that they may remain in business. This analysis therefore limits the estimation of state revenue impacts to four sources of revenue from IMPLAN's standard reporting that would likely change due to reduced economic activity in the aftermath of a spill: (1) social insurance tax (e.g., unemployment tax); (2) sales tax; (3) corporate profits tax, and (4) personal income tax.

RESULTS

Following the approach presented above, this analysis estimates the employment, GDP, income, and state revenue impacts associated with each of the oil spill scenarios outlined in Chapter 2. For each of these categories of impact, the analysis captures direct, indirect, and induced effects. The results of the analysis are presented in Exhibits 7-5 through 7-8. The range of impacts presented in each exhibit reflects the underlying ranges in recreational and commercial fishing impacts presented in Chapters 3 and 4, respectively (e.g., the reduction in recreational boating trips estimated as a range in Chapter 3). In addition, these impacts reflect impacts realized within Delaware only.

As indicated in all four exhibits, the patterns of impact closely mirror those presented in Chapters 3 and 4 for coastal and marine recreation and commercial fishing. The estimated economic impacts of spills are generally highest for oil spills occurring off the coast of Delaware, reflecting the more significant reductions in recreational and commercial fishing activity associated with these scenarios relative to those off the coasts of New Jersey and Virginia. The economic impacts of spills are also higher for spills occurring in the spring and summer than spills occurring in the fall or winter, consistent with the temporal distribution of recreational and, to a lesser extent, commercial fishing activity during the course of the year. The results in Exhibits 7-5 through 7-8 also show that economic impacts are, in most cases, higher for larger spills than smaller spills.

One exception to this pattern is the 200,000-barrel spills occurring off New Jersey in the summer. As shown in the exhibits, the economic impacts for these spills are lower than the corresponding impacts for the 126-barrel and 2,240-barrel spills. This result reflects how the worst-case spill is defined for each scenario. As described in Chapter 2, the specification for the worst-case scenario is based on the maximum shoreline oiled across the entire Mid-Atlantic region rather than the maximum shoreline oiling on Delaware's coast. In the case of the unmitigated 200,000-barrel summer spills off the coast of New Jersey, the maximum shoreline oiling is projected when currents and the wind carry the oil northward, causing significant oiling along New Jersey and southern Long Island, but no oiling around Delaware's coast. As a sensitivity analysis, the appendix to this report presents economic impacts under an alternative specification of the 200,000-barrel summer spills off the coast of New Jersey, using the same conditions as assumed for the 126- and 2,240-barrel worst-case spills.

EXHIBIT 7-5. NEGATIVE EMPLOYMENT IMPACTS FOR DELAWARE BY SPILL SCENARIO (PERSONS EMPLOYED)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	137 - 171	656 - 740	114 - 142	0 - 1
	Surface	Unmitigated 2,240bbl	331 - 445	1,481 - 1,596	532 - 633	0 - 2
	Surface	Unmitigated 200,000bbl	2,015 - 2,283	3,286 - 3,622	1,989 - 2,311	15 - 106
	Surface	Mitigated 200,000bbl	1,830 - 2,055	3,160 - 3,467	1,938 - 2,256	14 - 102
	Subsurface	Unmitigated 900,000bbl	5,610 - 5,710	5,636 - 5,772	3,201 - 3,323	3,757 - 3,801
New Jersey	Surface	Unmitigated 126bbl	-	653 - 741	-	0 - 1
	Surface	Unmitigated 2,240bbl	0 - 1	1,415 - 1,577	0 - 60	1 - 4
	Surface	Unmitigated 200,000bbl	2 - 5	1 - 2	106 - 336	41 - 285
	Surface	Mitigated 200,000bbl	2 - 5	0 - 1	1 - 3	1 - 3
	Subsurface	Unmitigated 900,000bbl	5,627 - 5,716	5,597 - 5,740	3,290 - 3,356	4,342 - 4,305
Virginia	Surface	Unmitigated 126bbl	-	0 - 43	-	-
	Surface	Unmitigated 2,240bbl	-	0 - 91	0 - 0	-
	Surface	Unmitigated 200,000bbl	0 - 1	105 - 434	2 - 7	-
	Surface	Mitigated 200,000bbl	-	2,139 - 2,307	1 - 6	-
	Subsurface	Unmitigated 900,000bbl	5,471 - 5,554	2,046 - ,2265	982 - 1,126	1,838 - 1,842

EXHIBIT 7-6. NEGATIVE GDP IMPACTS FOR DELAWARE BY SPILL SCENARIO (MILLIONS OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$8 - $10.2	$38.5 - $43.9	$6.7 - $8.6	$0 - $0.1
	Surface	Unmitigated 2,240bbl	$19.7 - $27.1	$87.5 - $94.8	$31.4 - $38	$0 - $0.1
	Surface	Unmitigated 200,000bbl	$119.2 - $136.5	$194.7 - $216.3	$117.4 - $138.4	$1 - $7
	Surface	Mitigated 200,000bbl	$108.2 - $122.7	$186.8 - $207	$114.2 - $134.9	$0.9 - $6.7
	Subsurface	Unmitigated 900,000bbl	$331.7 - $337.6	$335 - $343.3	$191 - $198.6	$222.2 - $224.8
New Jersey	Surface	Unmitigated 126bbl	$0	$38.3 - $44	$0	$0 - $0.1
	Surface	Unmitigated 2,240bbl	$0 - $0.1	$83.1 - $93.5	$0 - $4	$0 - $0.3
	Surface	Unmitigated 200,000bbl	$0.1 - $0.3	$0.1 - $0.2	$7 - $22.2	$2.7 - $18.8
	Surface	Mitigated 200,000bbl	$0.1 - $0.3	$0 - $0	$0.1 - $0.2	$0 - $0.2
	Subsurface	Unmitigated 900,000bbl	$332.6 - $337.9	$332.1 - $341.1	$196.6 - $200.5	$256.4 - $254.3
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $2.9	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $6	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$6.9 - $28.6	$0.1 - $0.4	$0
	Surface	Mitigated 200,000bbl	$0	$126.7 - $137.7	$0.1 - $0.4	$0
	Subsurface	Unmitigated 900,000bbl	$323.1 - $328.4	$119.9 - $134.3	$57.7 - $67.2	$107.7 - $107.9

EXHIBIT 7-7. NEGATIVE LABOR INCOME IMPACTS IN DELAWARE BY SPILL SCENARIO (MILLIONS OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$5 - $6.3	$24.1 - $27.4	$4.2 - $5.3	$0 - $0
	Surface	Unmitigated 2,240bbl	$12.3 - $16.7	$54.7 - $59.1	$19.6 - $23.6	$0 - $0.1
	Surface	Unmitigated 200,000bbl	$74.5 - $84.9	$121.5 - $134.5	$73.4 - $85.9	$0.6 - $4.1
	Surface	Mitigated 200,000bbl	$67.6 - $76.3	$116.7 - $128.6	$71.5 - $83.8	$0.5 - $4
	Subsurface	Unmitigated 900,000bbl	$207.4 - $211.2	$208.8 - $214	$118.8 - $123.5	$138.9 - $140.6
New Jersey	Surface	Unmitigated 126bbl	$0	$24 - $27.4	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$52.1 - $58.4	$0 - $2.3	$0 - $0.2
	Surface	Unmitigated 200,000bbl	$0.1 - $0.2	$0 - $0.1	$4.1 - $13.1	$1.6 - $11.1
	Surface	Mitigated 200,000bbl	$0.1 - $0.2	$0	$0 - $0.1	$0 - $0.1
	Subsurface	Unmitigated 900,000bbl	$208 - $211.4	$207.3 - $212.8	$122.3 - $124.8	$160.5 - $159.1
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $1.7	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $3.5	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$4.1 - $16.9	$0.1 - $0.3	$0
	Surface	Mitigated 200,000bbl	$0	$79.1 - $85.6	$0.1 - $0.2	$0
	Subsurface	Unmitigated 900,000bbl	$202.1 - $205.3	$75.4 - $83.9	$36.3 - $41.8	$67.7 - $67.9

EXHIBIT 7-8. REDUCTION IN DELAWARE STATE GOVERNMENT REVENUE BY SPILL SCENARIO (MILLIONS OF 2019$)

SPILL LOCATION	SPILL TYPE	SPILL SCENARIO	SPRING	SUMMER	FALL	WINTER
Delaware	Surface	Unmitigated 126bbl	$0.3 - $0.3	$1.3 - $1.5	$0.2 - $0.3	$0 - $0
	Surface	Unmitigated 2,240bbl	$0.7 - $0.9	$2.9 - $3.2	$1 - $1.3	$0 - $0
	Surface	Unmitigated 200,000bbl	$4 - $4.5	$6.5 - $7.2	$3.9 - $4.6	$0 - $0.2
	Surface	Mitigated 200,000bbl	$3.6 - $4.1	$6.2 - $6.9	$3.8 - $4.5	$0 - $0.2
	Subsurface	Unmitigated 900,000bbl	$11 - $11.2	$11.2 - $11.5	$6.4 - $6.6	$7.3 - $7.4
New Jersey	Surface	Unmitigated 126bbl	$0	$1.3 - $1.5	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$2.8 - $3.1	$0 - $0.2	$0
	Surface	Unmitigated 200,000bbl	$0	$0	$0.2 - $0.8	$0.1 - $0.6
	Surface	Mitigated 200,000bbl	$0	$0	$0	$0
	Subsurface	Unmitigated 900,000bbl	$11 - $11.2	$11.1 - $11.4	$6.6 - $6.7	$8.5 - $8.4
Virginia	Surface	Unmitigated 126bbl	$0	$0 - $0.1	$0	$0
	Surface	Unmitigated 2,240bbl	$0	$0 - $0.2	$0	$0
	Surface	Unmitigated 200,000bbl	$0	$0.2 - $1	$0	$0
	Surface	Mitigated 200,000bbl	$0	$4.2 - $4.6	$0	$0
	Subsurface	Unmitigated 900,000bbl	$10.7 - $10.9	$4 - $4.5	$1.9 - $2.3	$3.6 - $3.6

Exhibits 7-9(a) and 7-9(b) show—for economic impacts related to recreation and commercial fishing, respectively—the estimated distribution of impacts between direct, indirect, and induced effects. The distributions shown in the exhibits hold across spill scenarios due to the linear relationships between inputs and outputs in input-output models such as IMPLAN. As the exhibits show, direct impacts make up between 57 and 76 percent of impacts while indirect and induced effects make up between 24 and 43 percent of impacts, depending on the measure. The distribution between direct, indirect, and induced effects varies across measures for a variety of reasons, including differences in wages per worker between directly affected industries and other industries and differences in the labor-intensity of directly affected industries and indirect/induced activities. Direct impacts are highest for employment, reflecting the high degree of labor intensity of industries directly dependent on coastal and marine resources (e.g., restaurants in coastal beach towns).

EXHIBIT 7-9(a). DISTRIBUTION BETWEEN DIRECT, INDIRECT, AND INDUCED EFFECTS - ECONOMIC IMPACTS RELATED TO RECREATION

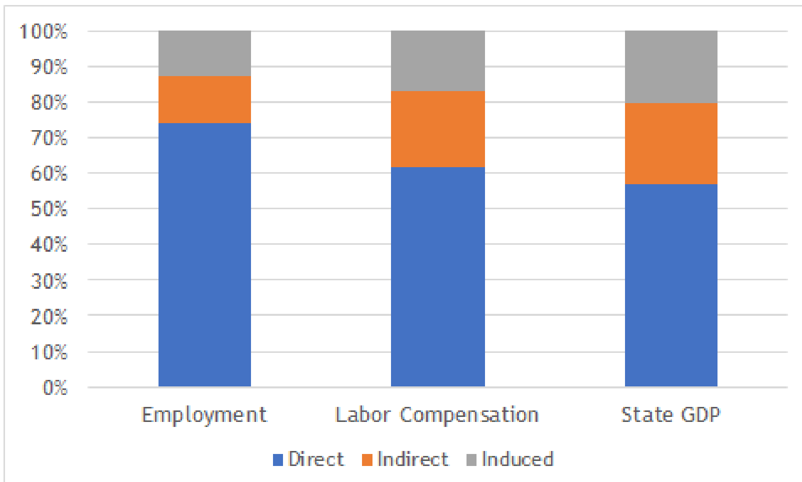
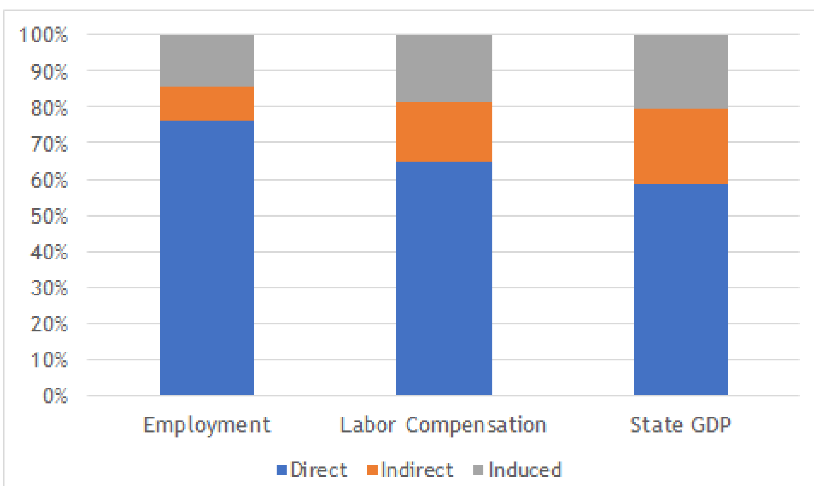
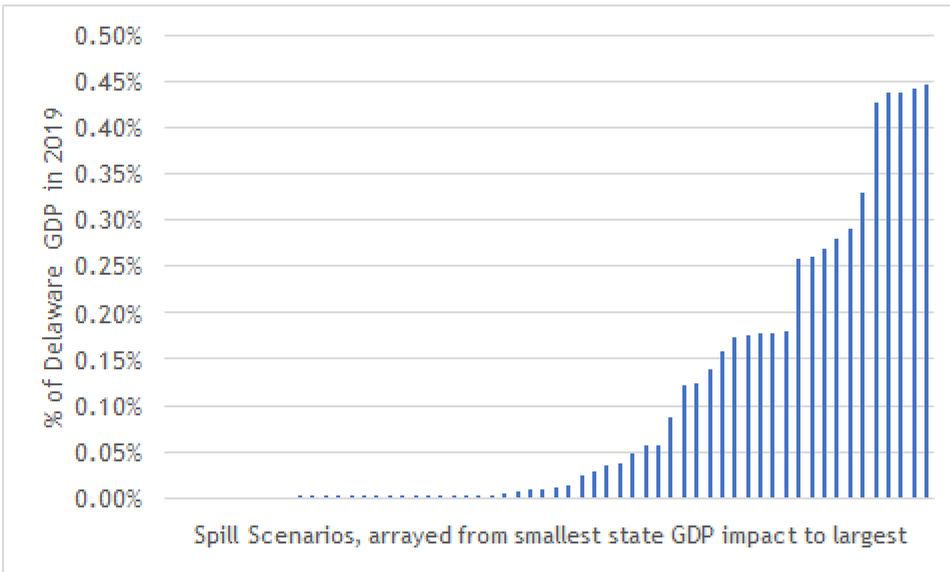


EXHIBIT 7-9(B). DISTRIBUTION BETWEEN DIRECT, INDIRECT, AND INDUCED EFFECTS - ECONOMIC IMPACTS RELATED TO COMMERCIAL FISHING



As further context for the results shown in Exhibits 7-5 through 7-8, Exhibit 7-10 presents the high end of the estimated state level GDP impacts by spill scenario as a percentage of Delaware state GDP in 2019. The spill scenarios are arrayed in the exhibit from smallest state GDP impact to largest. These results show that, at the high end, a large (900,000-barrel) spill could result in a 0.44 percent reduction in state GDP for the Delaware economy. As a point of comparison, Delaware GDP grew by 2.1 percent in 2018 and 1.8 percent in 2019.[39] Based on these figures, an oil spill near Delaware's coast could, at the high end, erode approximately one fifth of Delaware's economic growth in a given year.

EXHIBIT 7-10. SPILL-RELATED GDP IMPACTS FOR DELAWARE AS A PERCENT OF DELAWARE STATE GDP IN 2019



All oil spill scenarios are represented by the x-axis of this exhibit. Each bar represents a spill defined according to its location, spill size, and season. For presentational purposes, the scenarios are ordered from smallest to largest in terms of GDP impacts as a percentage of Delaware's GDP in 2019.

KEY UNCERTAINTIES

The analysis presented in this chapter highlights the economic and fiscal risk that various oil spill scenarios off the Mid-Atlantic coast may pose for Delaware. Although the analysis captures important direct and indirect connections between coastal and marine resources affected by a spill and different industries across Delaware's economy, the analysis is subject to a number of uncertainties, the most significant of which are as follows:

- As designed, the analysis does not capture ways in which different industries might adapt to an oil spill to minimize spill-related reductions in activity. For example, restaurants and bars might provide live music or other complimentary

[39] Changes in state level GDP from the U.S. Bureau of Economic Analysis, GDP by State, https://www.bea.gov/data/gdp/gdp-state.

entertainment more frequently to attract visitors. This and other economic adaptations are unlikely to fully offset a spill-related reduction in activity but may help limit the adverse impacts of a spill. All else equal, not capturing these adaptations likely leads to overestimation of adverse economic and fiscal impacts.

- For the assessment of economic impacts related to recreation, this analysis excludes impacts associated with the purchase of highly durable items such as boats and second homes, under the assumption that such purchases are unlikely to be significantly affected by a spill that temporarily reduces recreational activity. A given spill, however, may potentially influence the purchase decision of some buyers of these items, in which case this analysis underestimates spill-related economic impacts.
- The analysis of fiscal impacts presented in this chapter excludes government revenue streams in IMPLAN that are unlikely to change in proportion to reduced economic activity, such as annual excise taxes on vehicles and periodic business license fees. The rationale for this approach is that businesses would continue to pay licensing and related fees so that they can remain open and attract customers once the spill impact period has passed. It is possible, however, that a spill could lead to the permanent closure of some businesses, causing a decline in state government revenue related to these fees. To the degree that this occurs, this analysis underestimates state government revenue losses.
- As described in the introduction to this chapter, this analysis does not estimate economic impacts associated with changes in commercial shipping activity or related to oil spill response. Shipping-related economic impacts would likely be linked to changes in the overall level of activity at Delaware ports, particularly if vessels re-route to other ports. The degree to which this would occur, however, is highly uncertain. With respect to spill response, an influx of response workers might temporarily lead to increased economic activity, though such effects would likely be short-lived.

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APPENDIX

ALTERNATIVE IMPACT ESTIMATES FOR SELECT OIL SPILL SCENARIOS

The scenario-specific impact estimates presented in Chapters 3 through 7 of this report reflect the worst-case wind and current conditions for each scenario. As described in Chapter 2, the worst case is defined based on a probabilistic (or stochastic) set of oil spill model simulations, with each spill trajectory modeled for a given scenario representing a different set of conditions at the time of and immediately following a spill. To capture natural variation in conditions, each simulation for a given scenario in the probabilistic analysis was based on conditions observed during a randomly selected calendar date between 1 April 2018 and 20 April 2020. Because conditions are often dependent on the season, and because the socioeconomic impacts of oiling are also dependent on the season, the probabilistic modeling was conducted on a seasonal basis. Thus, for each combination of spill location and spill size, one set of probabilistic runs was based on winds and currents observed on historical days in the summer, another set was based on conditions observed during fall days, etc.

After the probabilistic modeling was complete, the “worst case” (deterministic) spill event from each set of stochastic runs was chosen for the assessment of socioeconomic impacts. The identification of worst-case exposure conditions for a given spill size and location was based on the maximum length of shoreline oiled (with an oil concentration >1.0 g/m^2) among the stochastic simulations. Because the geographic scope of the oil spill modeling covers the broader Mid-Atlantic region, the worst-case scenario was based on the maximum shoreline oiled *across the entire region*. For a limited number of scenarios, the conditions that result in the maximum length of shoreline oiled for the region may not be the same conditions that result in the maximum amount of shoreline oiling for Delaware. This reflects the possibility that conditions leading to significant shoreline oiling north or south of Delaware may not necessarily result in significant oiling of Delaware’s shoreline.

This approach for defining worst-case conditions on a scenario-specific basis, as opposed to identifying worst-case conditions to apply to all spills for a given location and season, can in some cases lead to counter-intuitive results. In particular, as shown in the main body of this report, the estimated impacts for the 200,000-barrel summer spills off the coast of New Jersey are in some cases lower than the estimated impacts for the 2,240-barrel summer spill off New Jersey. For the 200,000-barrel spill, the maximum shoreline oiling is projected when currents and the wind carry the oil northward, causing significant oiling along the coast of New Jersey and the southern coast of Long Island, but no oiling to Delaware’s coast. Worst-case conditions for the 2,240-barrel and 126-barrel spills, however, are when the wind and currents push oil southward toward Delaware.

To assess spill impacts for worst-case conditions defined consistently between the 200,000-barrel summer spills off the coast of New Jersey and the 126- and 2,240-barrel scenarios, an alternative set of worst-case conditions was defined for the 200,000-barrel spills. Under this alternative specification, the worst-case conditions for the 126- and 2,240-barrel summer spills off New Jersey were applied to the 200,000-barrel scenarios as well. Based on this alternative specification, oil spill modeling was conducted for both the unmitigated and mitigated 200,000-barrel spills off the New Jersey coast and impacts for each impact category were re-estimated for these scenarios.

Exhibits A-1 and A-2 present the results of this alternative analysis and, for ease of comparison, the primary results included in the main body of this document. Based on the factors defining the low-end and high-end results described in Chapters 3 through 7, low-end estimates are presented in Exhibit A-1 and high-end results are presented in Exhibit A-2. As indicated in the exhibits, the alternative specification of worst-case conditions for the *unmitigated* 200,000-barrel summer spills off New Jersey lead to increased impact estimates across all categories of impact, relative to the primary results. For the mitigated scenario, however, the impact estimates for some impact categories (e.g., beach recreation) remain at zero. This reflects the effectiveness of mitigation measures to limit physical impacts that affect specific uses of marine and coastal resources (e.g., to limit shoreline oiling in the case of beach recreation).

EXHIBIT A-1. IMPACTS FOR 200,000-BARREL SUMMER SPILLS OFF NEW JERSEY - LOW END (MILLIONS OF 2019$, UNLESS OTHERWISE NOTED)

IMPACT CATEGORY	PRIMARY ANALYSIS		ALTERNATIVE ANALYSIS	
	UNMITIGATED 200,000bbl	MITIGATED 200,000bbl	UNMITIGATED 200,000bbl	MITIGATED 200,000bbl
Beach Recreation	$0	$0	$143,200,000	$0
Recreational Fishing	$0	$0	$1,900,000	$0
Recreational Boating	$0	$0	$7,300,000	$2,400,000
Commercial Fishing	$30,000	$10,000	$3,290,000	$2,580,000
Shipping	$0	$0	$207,000	$0
Response Costs	$0	$0	$61,520,000	$0
Economic impacts - DE employment (persons employed)	0	0	3,230	120
Economic impacts - DE GDP	$51,000	$17,000	$191,029,000	$7,763,000
Econ. Impacts - DE labor income	$30,000	$10,000	$119,413,000	$4,585,000
Economic Impacts - DE state revenue	$2,000	$1,000	$6,355,000	$272,000

EXHIBIT A-2. IMPACTS FOR 200,000-BARREL SUMMER SPILLS OFF NEW JERSEY - HIGH END (MILLIONS OF 2019$, UNLESS OTHERWISE NOTED)

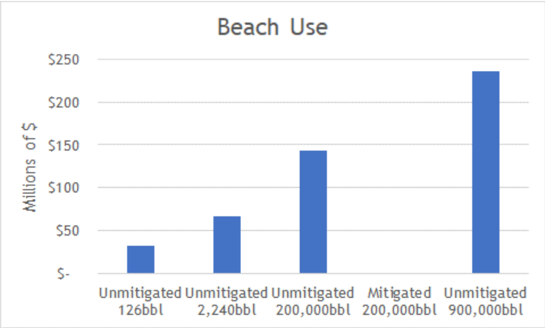
IMPACT CATEGORY	PRIMARY ANALYSIS		ALTERNATIVE ANALYSIS	
	UNMITIGATED 200,000bbl	MITIGATED 200,000bbl	UNMITIGATED 200,000bbl	MITIGATED 200,000bbl
Beach Recreation	$0	$0	$143,200,000	$0
Recreational Fishing	$0	$0	$3,600,000	$0
Recreational Boating	$0	$0	$12,100,000	$7,000,000
Commercial Fishing	$90,000	$20,000	$11,040,000	$8,650,000
Shipping	$0	$0	$566,000	$0
Response Costs	$0	$0	$113,530,000	$0
Economic impacts - DE employment (persons employed)	0	0	3,590	370
Economic impacts - DE GDP	$153,000	$34,000	$214,459,000	$24,497,000
Econ. Impacts - DE labor income	$91,000	$20,000	$133,475,000	$14,471,000
Economic Impacts - DE state revenue	$5,000	$1,000	$7,161,000	$852,000

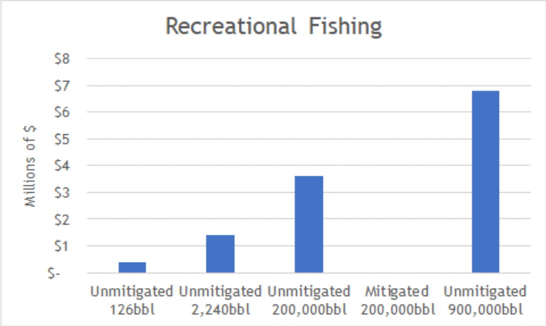
As additional context for the results presented in Exhibits A-1 and A-2, Exhibit A-3 shows the estimated high-end impacts for all of the summer spill scenarios off the coast of New Jersey, using the alternative estimates presented above for the 200,000-barrel scenarios.[40] As indicated in Exhibit A-3, the alternative impact estimates for the unmitigated 200,000-barrel summer New Jersey scenarios are, as expected, greater than the impact estimates for the 126-barrel and 2,240-barrel scenarios. This pattern stands in contrast to the results presented in the main body of this report for some impact categories, which showed higher impacts for the 2,240-barrel spill relative to the unmitigated 200,000-barrel spill. For most impact categories, the results in Exhibit A-3 show that impacts for the mitigated 200,000-barrel summer spill scenario off New Jersey are less than impacts associated with the 2,240-barrel scenario. This reflects the degree to which mitigation measures are projected to limit shoreline and surface oiling along Delaware's coast following a 200,000-barrel spill off New Jersey.[41]

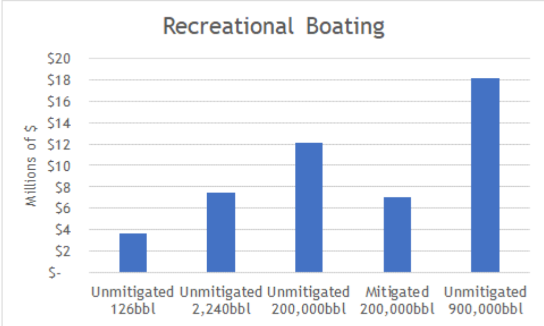
[40] Although Exhibit A-3 and the discussion in this paragraph focus on the high-end estimates of impacts, the pattern of results discussed here applies to the low-end impact estimates as well.

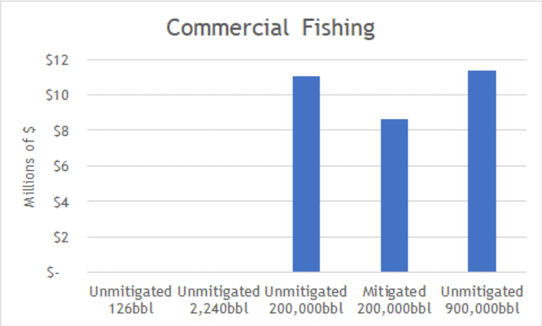
[41] For information on the mitigation measures assumed for this analysis, see RPS (2021a and 2021b).

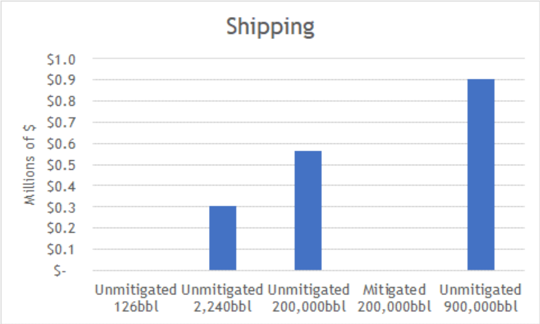
EXHIBIT A-3. HIGH-END IMPACT ESTIMATES FOR SUMMER SPILL SCENARIOS OFF NEW JERSEY, WITH ALTERNATIVE RESULTS FOR UNMITIGATED AND MITIGATED 200,000-BARREL SPILLS











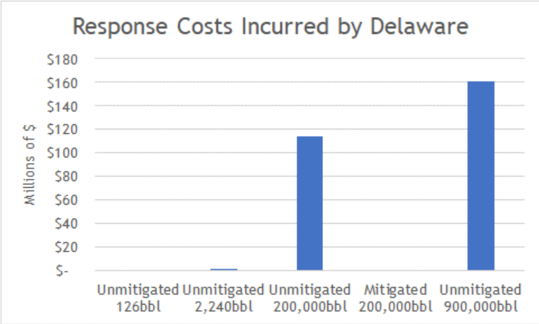


EXHIBIT A-3. HIGH-END IMPACT ESTIMATES FOR SUMMER SPILL SCENARIO S OF F NEW JERSEY, WITH ALTERNATIVE RESULTS FOR UNMITIGATED AND MITIGATED 200,000-BARREL SPILLS (CONTINUED)